AD-780 127

CONCEPT FEASIBILITY COMBAT TRACKED VEHICLE SIGNATURE DUPLICATOR

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Chrysler Corporation

Prepared for:

Army Mobility Equipment Research and Development Center

15 March 1964

UNCLASSIFIED
Security Classification

AD 780 127

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
   Chrysler Corporation
   Defense Engineering
   Box 1316, Detroit, Michigan 48231

2a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

2b. GROUP: N/A

3. REPORT TITLE
   CONCEPT FEASIBILITY
   COMBAT TRACKED VEHICLE SIGNATURE DUPLICATOR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
   Final Technical Report, 23 May 1973 to 15 March 1974

5. AUTHOR(S) (First name, middle initial, last name)
   Burton D. Jones
   Gerald T. Cohron

6. REPORT DATE: 15 March 1974

7a. TOTAL NO. OF PAGES: ~~[illegible]~~ 133

7b. NO. OF REFS: 8

8a. CONTRACT OR GRANT NO.: DAAK-02-73-C-0364

b. PROJECT NO.: N/A

c. N/A

d. N/A

9a. ORIGINATOR'S REPORT NUMBER(S): N/A

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report): AD-

10. DISTRIBUTION STATEMENT
    DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

11. SUPPLEMENTARY NOTES: N/A

12. SPONSORING MILITARY ACTIVITY
    U.S. Army Mobility Equipment Research and Development Center
    Ft. Belvoir, Virginia

13. ABSTRACT

MERDC has been investigating a family of combat vehicle mobility enhancement/mine clearing concepts to meet a well-documented mine threat. The CTVSD concept was recently added to the range of candidate systems and preliminary studies weremade jointly by MERDC and TACOM. This report presents the results of an investigation of the feasibility of a specialized tracked vehicle for application in certain mine-clearing missions. The concept depends on the redundancy of a quad-track, quad-drive locomotion system for the capability to continue operation after one or more mine detonations. The major conclusions are as follows:

- o CTVSD cross-country speed requirements can be met without undue compromise to other design requirements.
- o Soft soil mobility of various damaged configurations appears good and can be upgraded with later design revisions, especially those which increase roadwheel width and reduce gross vehicle weight.
- o It appears that a suspension system design can be developed that is capable of withstanding the specified blast threat. Testing is required to validate this conclusion.
- o Special devices, particularly liquid springs and crushable materials, show promise for upgrading blast resistance well beyond the specified threat.
- o The projected system is feasible from the design standpoint.

Major recommendations cite the needs for further threat quantification and tests of suspension system components in the blast environment.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
BLAST ENERGY ABSORPTION						
BLAST-RESISTANT VEHICULAR COMPONENTS						
COUNTERMINE VEHICLE						
CROSS-COUNTRY SPEEDS						
(OFF-ROAD TERRAIN)						
ENERGY ABSORBING MATERIALS						
FINITE ELEMENT ANALYSIS						
MANEUVERABILITY						
MINE BLAST						
MINE CLEARING						
MOBILITY						
RIDE DYNAMICS						
SIMULATION, MATHEMATICAL						
SOFT SOIL MOBILITY						
SUSPENSION DESIGN - TRACKED VEHICLES						
TORSILASTIC SPRINGS						
TRACKED VEHICLES						

CONCEPT FEASIBILITY COMBAT TRACKED VEHICLE SIGNATURE DUPLICATOR

1 MAY 1974

PREPARED FOR
US ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT CENTER
FT. BELVOIR, VIRGINIA

PREPARED BY
CHRYSLER CORPORATION
DEFENSE ENGINEERING
DETROIT, MICHIGAN

CONTRACT DAAK02-73-C-0364

EDITED BY: BURTON D. JONES
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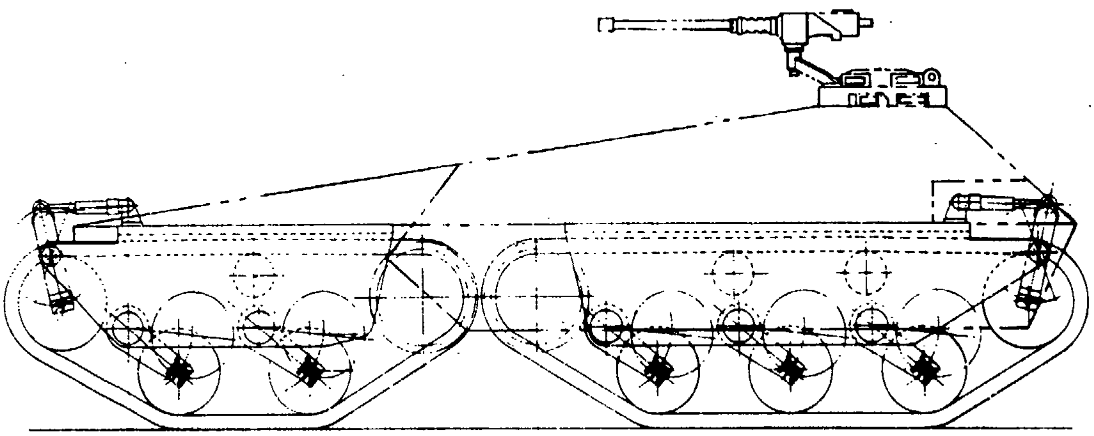

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FOREWORD

The analytical and design investigations covered in this report were conducted by Chrysler Defense Engineering (CDE) for the Countermine/Counter Intrusion Laboratory of the U. S. Army Mobility Equipment Research Development Center (USAMERDC), Ft. Belvoir, VA. The work was authorized under Contract DAAK02-73-C-0364, issued 23 May 1973.

The investigations were directed by the Chrysler Project Manager, Mr. Burton D. Jones, under the supervision of Mr. Henry F. McKenney, Manager of the Ordnance Systems Department. Mobility investigations were directed by the Mobility Research Department, supervised by Mr. G. T. Cohron, with key contributions made by Dr. P. W. Wheeler, Dr. L. P. Wolken, and Mr. C. S. Winters. Blast effects investigations were a joint effort by Mobility Research, Mr. R. F. Hughes of the Operations Research and Systems Analysis Department, and Mr. R. J. Thompson of Ordnance Systems. Mr. Thompson also led studies of special devices for energy management and played a coordinating role in analytical and design work. Design studies were accomplished under the supervision of Mr. R. M. Cory, with major contributions by Mr. H. A. Briggs and Mr. D. A. Charlebois. Design analysis and finite element Nastran modeling of CTVSD structure were supervised by Mr. J. D. Kochevar, with key contributions made by Mr. Sharad Kumar. Many others at CDE also made important contributions to the success of the project.

The project was directed for USAMERDC initially by Mr. David A. Vaughn and later by Mr. James C. Porterfield. Mr. James K. Miatech of the USATACOM Concept and Technology Division served as a vehicle design consultant for the Government. All three individuals contributed materially to the accomplishments described in this report.

1.0 SUMMARY

The analytical and design investigations covered in this report were conducted by Chrysler Defense Engineering for the Countermine/Counter Intrusion Laboratory of MERDC. The investigations were directed by the Chrysler Project Manager, Mr. B. D. Jones and for MERDC by Mr. D. A. Vaughn and Mr. J. C. Porterfield. Mr. J. K. Miatech of TACOM served as a vehicle design consultant.

1.1 INTRODUCTION

This report presents the results of an investigation of the feasibility of a specialized tracked vehicle for application in certain mine-clearing missions. The concept depends on the redundancy of a quad-track, quad-drive locomotion system for the capability to continue operation after one or more mine detonations.

Sections 2 through 4 of this report document the development process of the CTVSD. Section 5 presents the physical characteristics and a performance assessment of the current configuration. Section 6 contains a compendium of conclusions and recommendations.

Mines are a significant threat to personnel and combat vehicles. In Vietnam, 70 percent of all U.S. vehicle losses and about 33 percent of U.S. personnel casualties through 1970 were due to mines and booby traps. To meet this threat, MERDC has been investigating a family of combat vehicle mobility enhancement/mine clearing concepts for many years. The CTVSD concept was recently added to the range of candidate systems and preliminary studies were made jointly by MERDC and TACOM. An RFQ was issued in March 1973 for the further investigation of the CTVSD concept and Chrysler responded with a proposal in April. The contract was awarded 23 May 1973.

Because of the preliminary status of prior investigations and the exploratory nature of the planned program, detailed performance requirements were not stated in the contract. Several generalized requirements or directions were provided, summarized as follows:

- Signature properties that will approximate heavy combat vehicles
- Mobility performance equal to or greater than combat vehicles of 70,000 lbs and above
- Capability of surviving multiple encounters from mines up to 20 lbs
- The track section exposed to the detonation on the CTVSD can expect to be broken. The energy imparted to the suspension is expected to attain a maximum level of 100,000 ft-lbs.

- The roadwheels are to be 24 inches in diameter and weigh 270-300 lbs
- The main torsion spring will utilize rubber as the spring medium
- CTVSD must survive a mine detonation at any given suspension station without excessive damage to adjacent stations.

All contract requirements have been met in this program, including the particular accomplishments listed below:

- Adaptation of an advanced ride dynamics computer program
- Adaptation of a similarly advanced soft soil performance model
- Development of a simplified blast effects model
- Application of the models in parametric analyses
- Completion of preliminary design investigations to resolve problems in the input design concept
- Completion of tradeoff studies to define design approaches
- Definition of a potentially viable CTVSD baseline concept
- Detail design of a single suspension quadrant test rig
- Identification of promising special devices for energy management

It was anticipated that mobility would be a significant design constraint and that blast resistance would be limited. Later it became clear that ride-limited speed capabilities could be provided to allow CTVSD to stay ahead of current or product-improved tanks. The reason for this result is that the disadvantage of high unsprung weight is more than offset by advantages in all other parameters related to ride.

This permitted the design to be optimized for blast resistance to a greater degree than anticipated. The system will be capable of continued mine clearing operation after one or more detonations. Calculations indicate that the spring, roadarm, axle, bearings, and hub will survive the specified blast without damage. The only exception to this view of system blast resistance is that the suspension bracket structure is not adequate for extreme offset blast conditions. The solution to this problem lies in integration of the suspension support and hull structures. This forecast of mobility and blast resistance capability is considered encouraging in regard to the viability of CTVSD as a candidate mine-clearing system and further development is recommended.

1.2 ANALYTICAL DEVELOPMENT

1.2.1 Ride Dynamics Investigations

The major objective of the ride dynamics investigations was to assure that the vehicle to be developed would have a cross-country speed capability equal to or exceeding that of operational and development tanks. The effects of variation of suspension parameters, such as spring rates, damping rates, and wheel weights, were analyzed to approach an optimum vehicle design from a ride dynamics standpoint. The ride characteristics of the M60A1 and the M60A1PI (product improved) tanks were used for comparison purposes.

Chrysler has an operational ride dynamics model, developed to investigate the ride dynamics of tanks and other tracked vehicles and used extensively in the M60 series tank and other analyses. Several adjustments were made to allow for the peculiarities of the CTVSD vehicle configuration. The vehicle model was run over a mathematically synthesized random terrain, with the amplitude factor changed to produce different RMS roughnesses. The random terrain was preferred to actual terrains because these tend to have inherent periodicities. The computer model for the recommended configuration was subsequently run over well-known terrains from Fort Knox and Aberdeen Proving Grounds for comparison purposes. The major factor used in the evaluation of parametric computer runs was the driver's absorbed power, which is considered the best indication of ride quality.

The results of the ride dynamics investigations in tables I, II, and III show that the CTVSD is able to equal or exceed the speeds of the tanks used for comparison. No single factor accounts for the better performance of the CTVSD, but comparison of suspension characteristics in table II reveals that higher jounce, adequate damping, and different resonant frequencies combined to produce this desirable result.

TABLE I. COMPARISON OF RIDE-LIMITED SPEEDS, MPH

TERRAIN	CTVSD PRELIM	CTVSD CURRENT	M60A1	M60A1PI
Random 3" RMS	25-30	21	14	21
Random 5" RMS	9	6	6	8
Rocky (Ft. Knox)	14	6	2.5	12
Mild (Ft. Knox)	30-35	25	20	21
Medium (Ft. Knox)	25-30	25-30	14.5	16
Perryman (APG)	9	9	4.5	6.5

TABLE II. SUSPENSION CHARACTERISTIC COMPARISON

SPECIFICATION	CTVSD PRELIM	CTVSD CURRENT	M60A1	M60A1PI
Linear Spring Rate, lb/in	831	1058	1645	1185
Jounce Travel, in	10	10	7	10.5
Shock Absorber: Type	Linear	Linear	Linear	Rotary
Positions	All	All	1, 2, 6	1, 2 & 6
Pitch Natural Frequency, Hz	1.14	1.42	1.02	0.86
Bounce Natural Frequency, Hz	1.16	1.13	1.40	1.20

TABLE III. RIDE DYNAMICS DESIGN RECOMMENDATIONS

Parameter	Recom'd Level	Acceptable Range	Final Value
Spring Rate, in-lb/rad	300,000	300,000 - 400,000	381,338
Shock absorbers at wheel positions:	All	Corners	All
Damping curve: rate, lb-sec/in	350	250-600	1,340
blowoff-in jounce, lb	3,500	2,500-6,000	2,560
Roadwheel weight including 1/2 of roadarm, lb	Low as possible	1,000 max.	1,096
Mobility bump stop. lb:in	20,000:3	Not checked	40,000:3
Jounce travel, in	10	≥ 10	10
Gross vehicle weight, lb	70,000	As low as possible	95,859

1.2.2 Soft Soil Investigations

The objectives of the soft soil mobility investigations were:

- To define mobility performance characteristics of a baseline CTVSD
- To delineate the limiting mobility of undamaged and blast damaged configurations
- To determine vehicle design approaches that will improve capability

Soft soil performance was simulated by a computer program that analyzes the vehicle-ground interaction of a tracked vehicle in a steady-state situation, taking into account differential speed of the tracks. Soft soils are described in terms of Bekker parameters, and sinkage and resistance to forward motion are computed independently for the two sides of the vehicle. Program modifications were required to accommodate the segmented track and the presence of unpowered rigid wheels in the various CTVSD damage configurations.

A total of 25 configurations were evaluated, including the undamaged case for comparison. Nine of these cases were not considered separately because of symmetry and one was disregarded as trivial.

The soft soil mobility model originally used Bekker soil strength parameters but it was altered to accommodate unpowered rigid wheels, which required that soil strength also be stated in cone index terms. The analysis required that RCI be stated as an average for a layer of soil whose depth varies with the minimum width of the ground contact area. For uniformity in comparisons, the soil strength is specified for a fixed depth (in this case the 6" - 12" average, RCI_9). Soil values used in the program are based on data on West Germany. RCI values given primary emphasis were:

77 - Minimum strength feasible for mine-clearing

158 - Typical strength for normal operation

668 - Equivalent to hard soil or secondary road

The print-outs of the soft soil program are very extensive and include the values of all the input parameters and the resulting parameters that determine the vehicle speed. Each print-out covers seven values of soil strength, three slope levels, and two horsepower levels for the undamaged vehicle and the fourteen damaged configurations. The results for the initial and final configurations are summarized in the following table IV. The RCI_9=158 soil considered as the base line mine-clearing environment and the soil with RCI = 77 is considered the lowest strength in which mine-clearing would be feasible. Results are for zero slope and with the 450 HP engine. Analyses of the significance of these results are presented in section 3.2.5 for the initial configuration and section 5.2.2 for the final configuration.

TABLE IV. SUMMARY OF MOBILITY IN DEGRADED MODES

CONFIGURATION DESCRIPTION		CTVSD SPEED, MPH			
		Initial Configuration		Current Configuration	
RIGHT	LEFT	RCI = 77	RCI = 158	RCI = 77	RCI = 158
oo ooo	.o ooo	0	0	0	1.9
oo .oo	.o ooo	0	0	0	0
.o ooo	.o ooo	0	0	0	2.9
oo ooo	oo ..o	0	2.45	0	0
oo ..o	oo ..o	0	3.79	0	0
oo ooo	oo ooo	0	1.12	0	0
oo ooo	oo ooo	0	.40	2.1	4.5
oo ooo	oo ooo	0	2.23	2.8	5.2
oo ooo	oo .oo	2.61	5.18	0	0
oo ..o	.. ooo	10.16	16.07	7.0	13.5
oo ooo	oo ooo	3.83	6.11	0	0
oo ooo	.. ooo	10.82	16.34	7.3	13.5
oo .oo	oo .oo	4.08	6.27	0	0
oo ooo	oo ooo	5.21	8.03	0	0
oo ooo	oo ooo	17.68	23.21	13.5	21.3

1.2.3 Blast Effects Analysis

A simplified computer model of the CTVSD suspension unit dynamic response to mine detonation has been programmed for a digital computer. The blast effects model consists of a roadwheel set, roadarms, and hull masses with associated spring and damping constants. A torsilastic spring is included, along with a simplified representation of a shock absorber. The roadwheel and roadarm angular inertia effects are included.

The simulator computes resultant forces, moments, and motions based on input conditions which are approximations of the real physical conditions. Simplified approximations for input forces can be obtained. A nominal value of 100,000 ft-lbs of energy imparted to a suspension unit has been supplied by the Government, based on tests of countermine rollers exposed to mine blasts. A force acting over a period of time can be stated in terms of the area of the force-time curve, which is total impulse. The kinetic energy of the unit is 100,000 ft-lb and the total impulse for a nominal case is 2,250

lb-sec. The force and acceleration levels obtained from exercising this model are conservative and will be higher than from a model which considers elastic and plastic deformation properties of the structural numbers.

The blast effects model has been operated to obtain preliminary estimates of the dynamic response characteristics of the suspension unit in the vicinity of a mine detonation. Analysis of shock absorber and bump stop characteristics has provided insight into the blast effects condition. The roadarm weight was determined to be a major factor in the magnitude of the force transmitted through the bearings to the axle from the roadwheels. The relative force between the roadwheel and the roadarm is a function of the ratio of the roadwheel mass to the roadarm mass. The roadarm weight should be minimized to reduce forces and bending moments.

The evolved baseline concept employs break-away mobility bump stops and shock absorbers to absorb 14,000 lb-ft of blast-imparted energy, and crushable honeycomb wheel blast bump stops to absorb the remainder of wheel-roadarm kinetic energy. The entire 100,000 lb-ft of energy can be absorbed by the suspension system with a margin of safety in the present design.

The crew positions have a tolerable acceleration environment. Hull forces are nominal, and survivability of key mobility components appears assured.

1.2.4 Structural Analysis

Preliminary design analysis of CTVSD suspension and related structure has been performed throughout the design phase to ensure the structural adequacy of design. The complexity of design, the large number of loading environments, and uncertainties in load assumptions prompted the use of computer aided design techniques for CTVSD analysis. The following specific approach for analysis was planned:

- Development of finite-element computer model of hull and suspension
- Design analysis using conventional methods

The CTVSD hull and suspension structure has been modeled on a large-scale finite element design analysis program. The model includes plate, beam, and spring elements and consists of:

- 522 finite elements
- 494 nodes
- 2,470 degrees of freedom

The advantage of the finite-element model lies in its predictive capability and ease of evaluation of proposed modifications. Another advantage is that the same model may be used for various information such as deflection, stress,

buckling, vibration, transient, and random response. The primary application of the model will be in future phases since testing is essential to model validation.

As the study on CTVSD progressed, it became evident that blast survivability imposed the primary constraints on suspension design. Several stress analysis iterations have been performed in order to arrive at a balanced design. To avoid excessive loading of components, track centerguides were designed to fail at a predetermined load less than design load of other components. Based on this criterion, a 1.5 factor of safety in major suspension system components was achieved. Integration of the suspension support structure and the hull will be required to manage the blast loads from mines detonated near the edge of the track.

1.3 DESIGN INVESTIGATIONS

1.3.1 Preliminary Design

The baseline configuration for CTVSD is defined by TACOM layout LK-10371. The baseline configuration provided an excellent point of departure for further design investigations, oriented to the following design objectives:

- Preparation of an "Evolved Baseline Concept"

- Layouts and detail drawings of a test rig suspension system

Initial review of the baseline configuration resulted in identification of several problems, questions, or areas of incomplete definition. These were discussed by MERDC, TACOM, and Chrysler personnel in the early stage of the contract. These discussions provided guidance concerning which features of the baseline configuration were considered fixed and which characteristics could be altered in arriving at an improved design.

Chrysler prepared a sketch layout of a revised concept, reflecting our own tracked vehicle design experience and in particular our background in installation of torsilastic springs. The primary effects of changes were increases in vehicle length and track height. The length change was not a matter of serious concern, but considerable discussion attended the track envelope height. Other questions and problems were also discussed and adequately resolved in these initial discussions and the initial Chrysler concept was accepted as a sound basis for further design investigations.

Attention then turned to exploratory study of suspension element installations. Discussion with MERDC and TACOM personnel continued during this period and several conclusions or points of additional guidance emerged:

- Reduced track width (24-26") would be preferred.

- Reduced vehicle width would improve transportability.

- The track will fail upon mine detonation.

- The roadwheel tire will fail, but in a manner permitting continued operation.

- Each suspension unit must resist a detonation at an adjacent station.

Mobility studies showed that shock absorbers placed at each corner of the vehicle would provide acceptable mobility and also showed that more shock absorbers would improve mobility further. The shock absorber decision was also influenced by the desire to provide later for a specialized device to aid in dissipation of blast energy. Installation of an automotive shock absorber at each station provides a "space claim" for later integration of a specialized shock.

The first concept provided large rubber blocks above the track, to serve both as mobility bump stops and for absorption of blast energy. Two drawbacks were evident in this system:

- The moving track would be trapped between the stationary block and the wheel

- The Chrysler design concept increased the travel required to contact the stop and would cause spring failure

The corollary of the latter item is that additional space is available between the wheel and the track, allowing the bump stop to be installed therein. Studies led to the development of a dual bump stop concept in which mobility bump loads were taken on the roadarm and the high inertia loads resulting from blast resisted directly on the wheel.

The track chosen for the preliminary design was the basic T-97 track modified to a 30-inch width, which could be accomplished easily by one of two methods. The original 30-inch requirement was predicated on provision of a cleared path for tanks and other tracked vehicles with track width up to 28 inches. Later guidance was provided that track width should be 24-26 inches. Since a new 25-inch track design is available, preliminary investigations were halted at that point.

Working within the contract design constraints of a 24-inch roadwheel in the 270-300 lb range we designed an integral hub and roadwheel assembly with a total weight of approximately 750 lbs, allowing 150 lbs for the assembly. Further investigation led to the separate hub assembly with replaceable roadwheels discussed subsequently.

The preliminary baseline concept used a torsilastic spring. Spring design was straightforward and no problems were encountered.

Chrysler chose to use four identical idlers, two in front and two in the rear, permitting the track tension to be adjusted on all four quadrants by means of an M-60 track adjusting link.

1.3.2 Evolved Baseline Concept

The baseline concept evolved through the iterative interaction of design and analytical activities and through interaction of configuration constraints and detail design of test rig suspension elements. The baseline concept drawing is presented as the frontispiece. Dimensions, weights, and other key characteristics are presented in comparison with the initial TACOM/MERDC concept in table V. Suspension system elements are described in paragraphs to follow.

TABLE V. CONCEPT CHARACTERISTICS

CHARACTERISTIC	INITIAL	CURRENT
Idler Diameter - In	16.0	26.0
Support Roller Diameter - In	8.0	12.0
Idler at Rear	NO	YES
Track Adjustment/Rear	NO	YES
Track Adjustment/Front	NO	YES
Track Width - In	30.0	25.0
Shock Absorbers	4 Corners of Vehicle	All Positions
Sprocket Diameter - In	16.0	26.9
Blast Bump Stop	Rubber	Energy Absorbing Crushable Honeycomb Material
Separate Mobility Bump Stop	NO	YES
Vehicle Width - In	153.0	150.25
Ground Contact Length - In	199.0	215.9
Sponson Height - In	44.0	51.8

The feasibility of the shock absorber performing a dual function of mobility dampening and blast energy dissipation was investigated and it was determined that conventional shock absorbers could not perform both functions. One manufacturer may be able to design and produce a special hydraulic device capable of absorbing high blast energy, while still providing proper mobility dampening.

The bump stop on the evolved baseline vehicle was divided into separate mobility and blast systems to stop the roadarm and the wheel assembly. The mobility stop is a rubber compression spring on each arm that increases effective spring rate and provides a positive stop for normal vehicle operation. The blast stop has been located under the track and above the roadwheels, mounted to supporting members on the side plates. This position minimizes wheel bearing loads as the blast-driven wheel/arm assembly is stopped.

The track proposed for the baseline CTVSD is a 25-inch modification of the T142 type track. The track is completely designed at present and has undergone limited testing. The modified T142 track is a double pin, rubber bushed track with a pitch of 7.62 inches.

The roadwheel assembly was optimized by separating the wheels and hub. The roadwheel is 24 inches in diameter 6.75 inches wide, and has an estimated weight of 298 pounds. Other features include:

- A wide rim flange on the side for track guidance
- A molded rubber tire
- A symmetrical design to permit mounting in either position

In separating the wheel and hub several advantages were realized. The separate components allow easier assembly of roadwheel, replacement of a damaged roadwheel, and replacement of roadwheels without disassembly of the bearings. Radial loads pass through the centerline of the bearings. The roadwheel system is a promising area for further analytical and test investigations oriented to reduction of blast effects. The objective would be to provide for controlled yield or fracture of the roadwheel and/or attaching hardware.

The torsilastic rubber spring was used in the baseline concept with few changes. The spring rate was changed to compensate for changes in wheel loading and track tension and the physical size was changed to adjust the spring rate and conform with standard sizes for lower cost.

The track idlers are 26-inch diameter M60A1 roadwheels, suspended between dual pivoted arms, which can be adjusted with the M60A1 link to provide track tension.

In the initial concept, the support roller served as the idler in the rearmost position, but in the evolved concept the support rollers serve only as support

for the track. One support roller for the front quadrants and two support rollers for the rear quadrants are used. The support rollers use the M60A1 support roller wheel without the rubber tire.

Suspension support structure is adequate for vertical blast, but is not satisfactory for certain offset blast conditions. Resolution of this problem will require integration of the suspension support structure with the hull.

1.3.3 Test Rig Design

The test rig suspension system is essentialy identical with the front suspension quadrant of the baseline concept. Design of the test rig structure remains to be accomplished in a later program phase. It is planned to attach the suspension quadrant to an M728 Combat Engineer Vehicle for testing.

1.3.4 Special Devices

The CTVSD suspension system should minimize response to mine detonation occurring under the track and the resultant transfer of energy to the hull. Each suspension system unit should be as blast resistant as possible to prevent two adjacent units becoming immobilized with one mine detonation. Special devices exist which exhibit considerable promise in approaching these objectives.

The CTVSD concept is based on application of heavy roadwheels with large inertia used to react against the input impulse. If the roadwheel survives the blast, the next problem is to dispose of the stored energy with minimum effect on the vehicle. In addressing this problem, investigations were initiated into technological/industrial areas in which similar problems of energy management exist. A wide array of devices was identified for potential application to the CTVSD problem. Special devices to enhance the blast resistance characteristics have been grouped into four categories, discussed in the following paragraphs.

Hydraulic devices have been considered for application as replacements for standard mobility type shock absorbers. The liquid spring concept uses a special compressible fluid to achieve the spring function and special metering orifices to control flow past a piston head. Preliminary investigations indicate that a device occupying acceptable space and operating as a standard mobility type shock absorber may have the potential for absorbing the energy input to the suspension unit system. These devices are state-of-the-art and require little redesign for CTVSD blast conditions.

Crushable devices have been considered for application to the CTVSD suspension unit roadarm and roadwheel bump stops. Investigations of crushable honeycomb materials indicates that a wide variation in energy absorbing characteristics can be obtained for the bump stops.

Resilient devices considered for the concept include large rubber roadarm bump stops, designed to contact with the roadarm at 7 inches of jounce. This device is not an energy absorber and dissipator but an energy storer.

Frangible devices fracture in a prescribed manner. Fracture is a valid method of absorbing energy before such energy is transmitted to other structural members in the system.

1.4 SYSTEM CHARACTERISTICS

The process of defining a vehicle concept is essentially iterative, and several "point designs" have been established during definition of the current CTVSD concept. At each point in this process, we have initiated or redirected analytical and design studies to move to a more nearly optimum next-generation system.

The objective of this paragraph is to present a description of the capabilities and characteristics of the current concept. It should be noted that the current "Evolved Baseline Concept" is actually one point design in the process of final concept definition, which will be accomplished only after further test, design, and analytical work in future program phases.

1.4.1 Physical Characteristics

The general arrangement of the CTVSD evolved baseline concept is presented in the frontispiece. Table VI on the next page presents the physical and functional characteristics of the Evolved Baseline Concept incorporating the CDE suspension system and the TACOM/MERDC hull system. The data in this table, together with added details of spring and shock absorber dynamic characteristics, were used as inputs to a performance analysis of the evolved baseline concept.

1.4.2 Mobility

Ride investigations, at the point that recommendations were made to design engineering, indicated that reasonable component weight increases could be tolerated, from a vehicle ride standpoint, if necessary to improve blast survivability. The major changes from the preliminary to the current CTVSD are increased sprung and unsprung weights, increased suspension component weights, increased spring rate, and greater damping. Final adjustments of all inputs were made with latest estimates of component characteristics, weights, and locations. Comparisons of key ride dynamics inputs are shown in the following table VII.

TABLE VI CTVSD EVOLVED BASELINE CONCEPT, PHYSICAL CHARACTERISTICS

Overall Dimensions, Inches	
Length	313.88
Width	150.25
Height	
To sponson	51.81
To top of cupola	85.00
To top of machine gun	107.00
Width of track	25.00
Length of ground contact	
Front	38.12
Rear	76.24
Tread	109.00
Center of gravity, front front of vehicle	164.1
Total ground contact area, square inches	5,918
L/T Ratio	1.98
Weights (including magnetic signature blocks), Pounds	
Gross vehicle weight	95,859
Hull to sponsons	33,845
Sponsons to ground	62,014
Sprung Weight	80,577
Unsprung Weight	15,282
Wheel assembly (2 wheels and hardware)	814
Roadarm assembly (2 arms and hardware)	563
Suspension spring assembly	323
Ground loading at each wheel	9,586
Suspension spring rate, lbs per inch of wheel travel (1)	1,058
Jounce travel, inches	10.0
Natural frequencies of motion, Hertz	
Bounce	1.13
Pitch	1.42
Nominal unit ground pressure, PSI	16.2
VCI (2)	
For one pass	42
For 50 passes	104

Specific Power, Engine Flywheel Horsepower Per Ton	
450 HP engine (used in analysis)	9.4
600 HP engine	12.5
Shock Absorbers (tentative)	
Type	Linear, similar to M60
Locations	2 per wheel station
Blow-off force (at 1.7 inches per second), pounds	2,500
Damping force, (at 10 inches per second), pounds	
Jounce	3,250
Rebound	4,300
Stroke, inches	8.56
Mobility Bump Stops	
Type	Rubber
Locations	One for each roadarm
Total travel, inches	3
Force at full deflection, pounds	40,000
Blast Bump Stops	
Type	Covered aluminum honeycomb
Locations	Over each roadwheel
Initial crush force, per wheel station, pounds	463,200
Sustained crush force, per wheel station, pounds	231,600
Total crush travel, inches	5.3
Energy absorption per wheel station, lb-ft	102,000
Pitch Moment of Inertia of Sprung Mass about vehicle CG, inch-pound-second^2	896,613

(1) With the roadarm horizontal.

(2) Approximate soil strength (in terms of rating cone index averaged over the 6 to 12 inch depth) required to permit the specified number of passes of the undamaged CTVSD.

TABLE VII COMPARISON OF KEY INPUTS TO RIDE DYNAMICS ANALYSIS

PARAMETER	PRELIMINARY DESIGN	CURRENT CTVSD
Gross vehicle weight, pounds	70,000	95,859
Sprung weight, pounds	60,000	80,577
Unsprung weight, pounds	10,000	15,282
Roadwheel weight (includes 1/2 of roadarm weight, pounds	800	1,096
CG location, inches from front	157.0	164.1
Pitch Moment of Inertia of sprung mass about vehicle CG, in-lb-sec^2	1,000,000	896,613
Individual spring rate, in-lb/rad	300,000	381,338
Damping curve:		
rate - lb-sec/in	350	1,340
blowoff in jounce, lb	3,500	2,560
Shock absorber positions	all	all
Mobility bump stop, pounds: inches	20,000:3	40,000:3
Jounce travel, inches	10	10

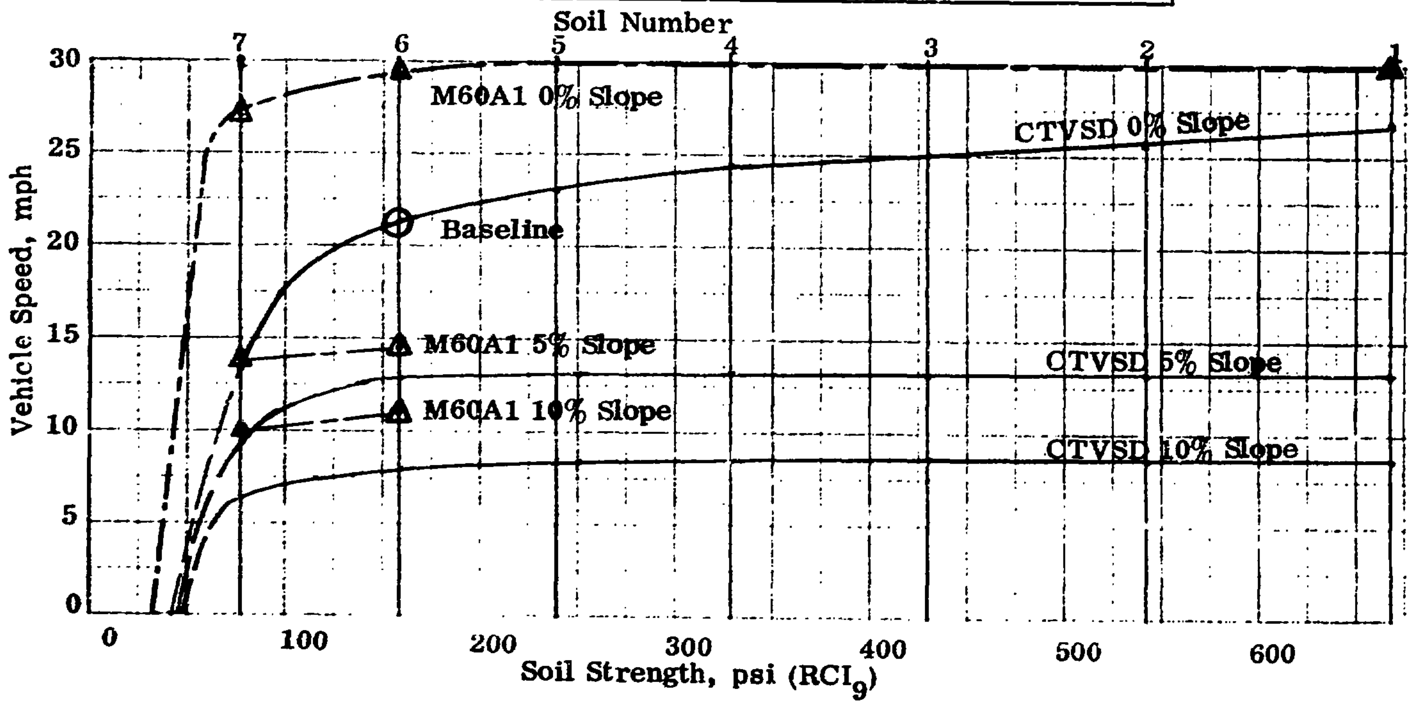
The effects of larger sprung mass, increased suspension spring stiffness and reduced moment of inertia are reflected in a comparison of pitch and bounce natural frequencies. Bounce natural frequency decreased from 1.16 to 1.13 Hz and pitch natural frequency increased from 1.14 to 1.42 Hz.

The net effect of all revisions has been slight reductions in the ride-limited speeds on most of the six terrains. Reduced V-ride speeds still compare favorably with the M60A1(PI) and are higher than M60A1 speeds as shown in paragraph 1.2.1.

The two major changes to the CTVSD that affect soft soil mobility are the increase in gross vehicle weight from 70,000 pounds to 95,859 pounds, and a 27.6 inch rearward shift in the center of gravity.

In the undamaged configuration, the current CTVSD with 450 HP achieves 21.3 mph under baseline conditions (RCI_9 = 158, 0% slope) compared with 29 mph for the M60A1. Assuming speed increase proportional to engine horsepower increase, a CTVSD with 600 hp would have equal speed capability on the level and slightly greater speeds on the slope compared to the M60A1. The current CTVSD shows less speed potential and will require more horsepower to equal M60A1 performance (see following figure).

At RCI_9 = 158 & 0% Slope		Left		Right	
		Front	Back	Front	Back
Quad Loading, lbs.		19,225	28,706	19,224	28,705
Sinkage, inches		1.3	0.9	1.3	0.9
Mean Ground Pressure, psi		20.2	15.1	20.2	15.1
Gross Traction, lbs.		23,427		23,426	
Drag, lbs.		794		794	
% Slip At	0% Slope	1.3		1.3	
	5% Slope	4.3		4.3	
	10% Slope	7.3		7.3	
Steering Effort, %		0			



Soft Soil Mobility Comparison of M60A1 and Current CTVSD

Table VIII on the next page presents comparative data on the effects of blast damage on speeds of the preliminary and current CTVSD's in three soils and on two terrain slopes. There are at least two significant trends in these data. First, the equalization of wheel loads definitely increases the number of "go" con[illegible]urations having front quadrant damage, even with higher vehicle weight. This is accomplished at the expense of reduced mobility of configurations having damage to rear quadrants, the less probable condition.

Secondly, it is apparent that mobility is maintained, especially in the more important stronger soils, for extensively damaged configurations. The configurations cover all those having at least one intact quadrant per side after having sustained up to five mine blasts. The probabilities of retaining acceptable mobility after repeated blast exposures appear favorable.

The soft soil mobility of a CTVSD with untracked wheels will be improved by increasing wheel width. A similar reduction in load carried by the wheel will have a similar effect on motion resistance. Because of the difficulty of providing a blastworthy design with reduced weight, it is logical to increase roadwheel width for improved soft soil mobility. Increased roadwheel width has another advantage in that it will provide greater protection to trailing undamaged quadrants. Weight reduction should also be considered as a method of further improving performance, but is not evident that weight reduction is essential to achieve an effective CTVSD.

1.4.3 Blast Resistance

The blast effects model input data was updated to the current CTVSD configuration including weights, geometries, and functions of components. The computer analysis of motions and forces of the hull and suspension components has corroborated the adequacy of the design to manage the specified blast energy with an adequate margin. The effects of a blast under the number one wheel are summarized in table IX. If the blast occurs under the front roadwheel as assumed here, the crew is well isolated from the blast. While hull bounce acceleration produces an upward acceleration, the pitch acceleration counteracts this effect since the crew is located 110 inches behind the CG. Another important fact is illustrated in the table. The total energy of the blast is absorbed before the wheel bump stop has been fully crushed. Of the 5.3 inches of crush available, 2.7 inches were used, leaving a margin of unused energy absorption capacity.

The credibility of the results of this analysis depend upon the quality of the input assumptions. These should be validated by field measurements. If the assumptions prove to be accurate, then it is apparent that a structure can be designed to manage the blast energy, leaving critical components intact for continued mine-clearing operation.

TABLE VIII SOFT SOIL MOBILITY OF TWO CTVSD CONFIGURATIONS
(Miles Per Hour for Specified Configuration and Operating Condition)

Configuration No.	No. of Blasts Sust'd.	Blast-damaged Configuration: Right — Left	$RCI_9 = 77$				$RCI_9 = 158$				$RCI_9 = 668$			
			0% SLOPE		10% SLOPE		0% SLOPE		10% SLOPE		0% SLOPE		10% SLOPE	
			Prelim[6]	Current[6]	Prelim	Current	Prelim	Current	Prelim	Current	Prelim	Current	Prelim	Current
Front Only Damage														
D1	1		0	2.1	0	0	0.4	4.5	0	1.9	19.9	10.4	8.0	6.0
A1	2		0	2.8	0	0	2.2	5.2	0	3.2	20.8	20.7	9.8	7.4
E1	2		0	0	0	0	0	1.9	0	0	9.8	10.2	5.7	5.2
(1)	3		0	1.4	0	0	1.1	4.0	0	1.6	16.2	16.2	8.0	6.4
F1	3		10.8	7.2	6.5	5.1	16.3	13.5	8.7	6.4	21.3	21.2	9.9	7.6
B1	4		0	0	0	0	0	2.9	0	0	11.5	11.8	6.2	5.4
Front and Rear Damage														
A4	2		0	0	0	0	1.1	0	0	0	19.5	13.0	7.5	2.1
(2)	3		0	0	0	0	0	0	0	0	15.5	10.3	7.2	1.0
(2)	3		0	0	0	0	0	0	0	0	15.5	10.3	7.2	1.0
B3	4		0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(C3)	4		16.2	7.0	6.4	4.8	16.1	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(B3)	4		0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(B3)	5		0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(C3)	5		10.2	7.0	6.4	4.8	16.1	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(C3)	5		10.2	7.0	6.4	4.8	16.1	13.5	8.6	6.1	21.3	21.2	6.8	5.8
Rear Only Damage														
D2	1		3.4	0	0	0	6.1	0	1.8	0	21.3	13.0	5.9	2.1
A2	2		5.2	0	0	0	8.0	0	3.2	0	24.8	15.2	9.9	4.0
E3	2		2.6	0	0	0	5.2	0	0	0	21.1	6.4	5.8	0
(3)	3		4.6	0	0	0	7.2	0	0	0	23.6	13.2	9.6	2.0
F3	3		0	0	0	0	2.4	0	0	0	13.3	0	4.8	0
B2	4		4.1	0	0	0	6.3	0	0	0	22.3	11.2	9.3	0
(B2)	4		4.1	0	0	0	6.3	0	0	0	22.3	11.2	9.3	0
(C3)	4		10.2	7.0	6.4	4.6	16.1	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(4)	5		2.0	0	0	0	5.0	0	0	0	18.8	5.6	8.0	0
No Damage														
OK	0		17.6	13.5	9.0	6.5	23.2	21.3	10.7	8.0	27.2	25.8	11.4	8.6

(1) Average of A1 and B1
(2) Average of A4 and B3
(3) Average of A2 and B2
(4) Average of B2 and C2
(5) Key to blast damage pictograms:
- oo = Quadrant intact
- oo = Track missing, wheels intact
- . = Wheel (and track) missing
- x = Indicated quadrant carries no load

(6) Key to 450 Hp CTVSD designs:

CTVSD	GVD, Lb.	CG Location Inches from Front	Roadwheel Loading, Lb. Front	Roadwheel Loading, Lb. Rear	Track Width, In.
Preliminary	70,000	136.5	9,721	5,168	28
Current	95,459	164.1	9,586	9,586	35

TABLE IX. EFFECTS OF SPECIFIED BLAST ON CTVSD

TIME, MSEC	ITEM	MAXIMUM VALUE
1	Vertical force on hull, pounds	126,000
1	Hull bounce acceleration, g	2.6
1	Hull pitch acceleration, radians per sec^2	32.6
0	Driver vertical acceleration, g (110 inches rearward of CG)	-7.3
1	Vertical force on roadarm, pounds	385,000
6	Roadwheel velocity, inches per second	784
36	Windup of torsilastic spring, degrees	61.9
36	Roadwheel travel, inches (19.5 possible)	16.9
36	Crush of roadwheel bump stop, inches (5.3 possible)	2.7

1.5 CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of the study program are as follows:

- CTVSD cross-country speed requirements can be met without undue compromise to other design requirements.
- Soft soil mobility of various damaged configurations appears good and can be upgraded with later design revisions. Further evaluation should be tied to threat and system effectiveness studies.
- It appears that a suspension system design can be developed which is capable of withstanding the specified blast threat. Testing is required to validate this conclusion.
- Special devices , particularly liquid springs and crushable materials, show promise for upgrading blast resistance.
- The projected system is feasible from the design standpoint. Further work on structural integration and investigation of special devices and wider roadwheels is required.

Recommendations include:

- Refine and validate the blast effects model
- Conduct structural integration studies
- Continue investigation of special energy management devices and wider roadwheels

- Design a blast test fixture

- Evaluate projected capabilities in relation to the threat and to alternate systems

The conclusions and recommendations presented above have an analytical/investigative orientation, since they are the product of a program comprised of analytical and design investigations. This orientation should not obscure the fact that the true imperative for continued progress is acquisition of blast test data on the test rig system. The other recommendations are subordinate to this imperative and are suggested primarily as a method for making additional progress during the period of hardware procurement. On this basis, the time-sequenced recommendation for a future program is as follows:

- Design blast test fixture

- Continue blast effects model refinement and design investigations

- Procure and assemble test rig hardware

- Conduct first-generation tests

These tests should be exploratory rather than definitive. It is probable that further rig tests will be recommended later.

CTVSD feasibility remains to be demonstrated in hardware and it is not yet clear that the system will be effective in relation to other systems. The current view is sufficiently encouraging, however, to justify the recommendation that a program including the elements listed above be initiated. The reasons for this recommendation include:

- Studies by MERDC indicate that CTVSD is relatively effective against classic mine fields.

- CTVSD is the only known conceptual mine-clearing system that does not degrade base vehicle mobility

- CTVSD is the most viable concept in view for high speed mine-clearing of roads

- CTVSD has exceptional promise for defeating multiple-impulse mine fuses.

2.0 INTRODUCTION

This report presents the results of an investigation of the feasibility of a specialized tracked vehicle for application in certain mine-clearing missions. The concept depends on the redundancy of a quad-track, quad-drive locomotion system for the capability to continue operation after one or more mine detonations. The ultimate vehicle is intended to duplicate ground pressure, individual wheel loading, magnetic flux, and other signatures of various heavy combat vehicles, such that cleared paths can be provided for crossing minefields.

2.1 BACKGROUND

Mines are a significant threat to personnel and combat vehicles, as delineated in the USACDCENA March 1972 document quoted below:

> The Threat: Land mines have been used by most Armies which have engaged in combat since World War I. That they have been effective is indicated by the following facts:
>
> 1) 20.7% of all allied tank casualties in WW II were caused by mines. In Italy and in the Pacific Theatres of operations, where mountains and other natural obstacles restricted avenues of approach, tank casualties to mines were as high as 27.5% and 33%, respectively. At times during large scale offensive actions which necessitated the capture of fortified positions, tank casualties due to mines reached 40%. At the same time, personnel casualties due to mines ranged from about 1% in the Pacific and 3% in Europe to 4.4% in the Mediterranean Theatre.
>
> 2) In the Korean Conflict, UN tank casualties due to mines ranged as high as 70% during UN advances against the enemy. Personnel casualties to mines went as high as 10% during these UN attack/advance operations.
>
> 3) In Vietnam, 70% of all US vehicle losses and about 33% of US personnel casualties through 1970 were due to mines and booby traps.

USAMERDC has been seriously investigating a family of combat vehicle mobility enhancement/mine-clearing concepts for many years. These include the Track Width Mine-Clearing Plow, Fuel Air Explosives and the Mine-Clearing Roller.

The CTVSD concept was recently added to this range of candidate systems and was studied jointly by MERDC and TACOM. The initial results of these studies were summarized in ref (1) and the concept was then further refined into

TACOM drawing LK-10371, dated 6 February 1973 and presented herein as figure 1. This concept uses two redundant independently-driven tracks on each side. The forward track envelopes have two roadwheels, a front idler, and sprockets on the central final drive. The rear envelopes have three roadwheels and no idler. The suspension features 10 inches of jounce travel, using torsilastic springs. The hull provides armor protection for the two-man crew at approximately MICV level. This design represented the baseline for further development by CDE. We were also provided the following references as further background for our investigations:

(1) James K. Miatech, Countermine Deceiver Vehicle, USATACOM Technical Report No. 11670, dated September 1972.

(2) David A. Vaughn, Robert Felts, Army Countermine Mobility Equipment System (ACMES), USAMERDC Report No. 2018, dated November 1971.

(3) David A. Vaughn, System Effectiveness Study, Baseline Mine Clearing Systems and Tracked Vehicle Signature Duplicator Program, USAMERDC Briefing, dated November 1972.

(4) Bruce L. Morris, Evaluation of Nonexpendable Mine Clearing Roller Wheels Under Blast Attack, USAMERDC Report No. 2005, dated April 1971.

(5) A. B. Wenzel, E. D. Esparza, Measurement of Pressures and Impulses at Close Distances from Explosive Charges Buried and in Air, SWRI Final Report, dated 21 August 1972 (Contract No. DAAK02-71-C-0393).

(6) Hans R. Fuehrer, John E. Cunningham, Reduction of Blast Effects on Mine Neutralization Equipment, Martin Marietta Aerospace Corporation Interim Report, dated October 1972 (Contract No. DAAK02-72-C-0336).

(7) A. B. Wenzel, L. R. Garza, Lightweight Nonexpendable Mine Clearing Roller, SWRI Confidential Final Report, dated December 1972 (Contract No. DAAK02-70-C-0579).

A forthcoming report by D. A. Vaughn was furnished to Chrysler in draft form in September 1973 and provided excellent additional guidance concerning program approach.

RFQ DAAK02-73-C-1522 was issued in March 1973 for the further investigation of the CTVSD concept and Chrysler responded with a proposal on 19 April. Contract DAAK02-73-C-0364 was awarded 23 May 1973.

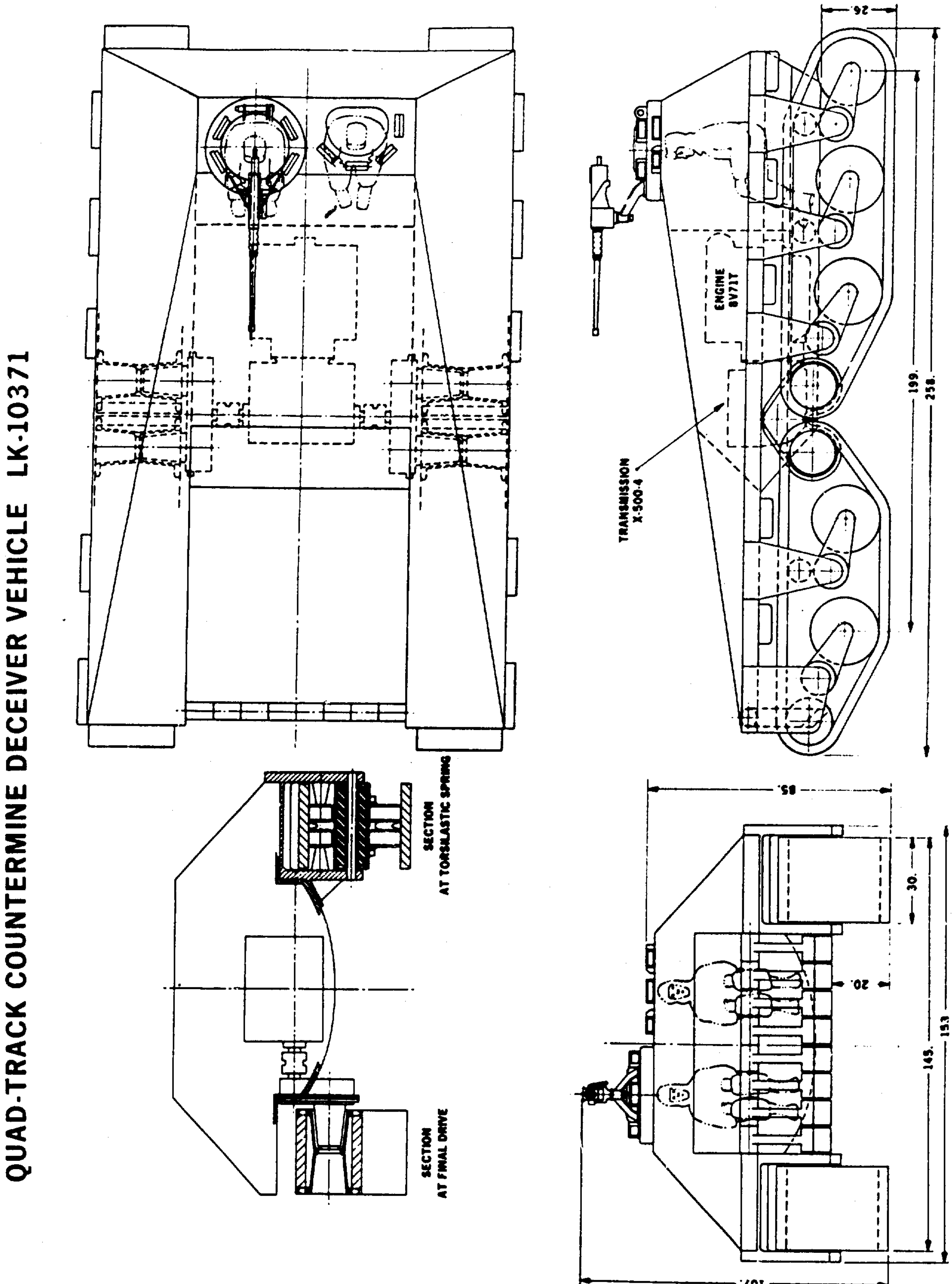


Figure 1 TACOM/MERDC CTVSD Concept

2.2 CONTRACT SCOPE

The contract requires the following supplies/services:

0001 Demonstrate a developed computer simulation package that will determine and display the mobility performance characteristics specified within Attachment "1" hereto, for the Combat Tracked Vehicle Signature Duplicator (CTVSD).

0002 Define (in technical terminology) and develop from the technical characteristics within attachment 1 hereto, and from the configuration reflected in appendix I thereto, an overall and detail engineering design concept of the CTVSD.

0003 Data, as specified in exhibit A and enclosures thereto.

1) Attachment 1 - USAMERDC Purchase Description for Combat Tracked Vehicle Signature Duplicator (CTVSD) dated 29 January 1973, with Appendix I consisting of LK10371 dated 6 February 1973 and LK10371 dated 1 March 1973.

2) Exhibit A - DD Form 1423 (Contract Data Requirement List).

Chrysler proposed that the program be organized in terms of four major tasks and several subtasks in arriving at the three deliverable contract end items. These tasks are summarized below:

End Item	Task	Task/Title/Description
0001	1	Computer Model Adapt existing computer models to reflect quad-track and to account for roll effects
0002	2	Evolved Baseline Concept
	2.1	Operate Computer Model Operate models as an aid in optimizing design parameters
	2.2	System Tradeoffs Conduct engineering investigations to define system parameters
	2.3	Concept Layout Prepare detailed layout of evolved concept
	3	Test Rig Design

3.1 Test Rig Analysis
Review CTVSD concept and design of government test fixture to establish requirements for test rig

3.2 Test Rig Layout
Prepare detailed layout indicating manner in which evolved concept will be simulated and integrated with test fixture

3.3 Detailed Drawings
Prepare details of all test rig suspension components and interface hardware

0003 4 Data

4.1 Cost and Performance Reports
Provide monthly reports per DD 1423-A001

4.2 Draft Technical Report
Provide two copies of draft report for government review

4.3 Final Technical Report
Integrate corrections and provide Type III Report in 40 copies plus one reproducible per DD 1423-A002

4.4 Initial Drawings and Lists
Provide single set of drawings and lists prepared in Tasks 2 and 3 for government review

4.5 Final Drawings and Lists
Revise drawings and lists as required and deliver three regular sets and one reproducible set per DD 1423-A003

These proposed tasks provided the framework within which the program has been conducted, with the exception that the government test fixture design (Task 3.1) was not provided.

2.3 CTVSD PERFORMANCE REQUIREMENTS

Because of the preliminary status of prior investigations and the exploratory nature of the planned program, detailed performance requirements were not stated by the Government. The purchase description did provide several generalized requirements or directions, extracted as follows:

"The requirement is for the final, production configuration of the CTVSD to have certain signature properties that will approximate similar properties of heavy combat vehicles operating in combat formation with the CTVSD. The Government interprets this requirement to mean that the final vehicle configuration should incorporate maximum flexibility for adjustment of these signatures within 10 percent of the average magnitude of the same signature for any combat vehicle of gross combat weight of 70,000 lbs and above.

"The requirement is for the final production configuration of the CTVSD to have mobility performance equivalent to or greater than combat vehicles of 70,000 lbs and above operating in combat formation with the CTVSD.

"The requirement is for the final production configuration of the CTVSD to be capable of surviving multiple mine encounters from mines up to 20 lbs high explosive (C-4) buried up to 2 inches below the surface of the ground and mines up to 10 lbs of high explosive (C-4) laid on the surface.

"The track section experiencing the detonation on the CTVSD can expect to be broken (severed) so that the final drive of that section cannot provide tractive power for the vehicle. The energy imparted to the wheel and suspension components directly above the point of detonation is expected to attain a maximum level of 100,000 ft-lbs as a result of the blast wave and collision with the track.

"The general requirements for the CTVSD are for a vehicle capable of: (1) reasonable cross-country mobility and flexibility for future improvement in this area of performance; (2) signature properties similar to those of combat vehicle of similar and greater weight with flexibility to adjust or tune these basic signatures to those of heavy combat vehicles in the weight class of 70,000 to 110,000 lbs; and (3) a capability for sustaining multiple mine detonations and continue to perform its basic mine clearing mission, which simply stated is to detonate most mines in its path.

"The road wheels are constrained to be 24 inches in diameter (including any rubber tire) and weigh not more than 300 lbs and not less than 270 lbs. Previous MERDC studies with roller wheels indicate that a wheel meeting these requirements and fabricated as specified in the reference documentation will survive in the near field of a 20 lb mine blast. The detail design of this wheel should closely follow design concepts for roller wheels contained in the literature.

"The main torsion spring will utilize rubber as the spring medium. Rubber has been selected because of: (1) energy absorbing properties; (2) reaction under high impulse loads; (3) simplicity in spring design and configuration; (4) estimated low cost and maintenance; and (5) potential life as a suspension system".

Discussions during the contract period made one other requirement clear. CTVSD must survive a mine detonation at any given suspension station without excessive damage to adjacent stations. If such damage occurs, the redundancy that is basic to the concept would be lost and the system no longer considered viable.

2.4 LIAISON WITH MERDC AND TACOM

Review meetings with MERDC and TACOM personnel were held at CDE during the period of performance. Close liaison was maintained initially with meeting intervals extending as the need for guidance diminished. The review meetings have contributed significantly to contract accomplishments and to keeping activities in accord with Government objectives.

2.5 ACCOMPLISHMENTS

All contract requirements have been met in this program, including the particular accomplishments listed below:

- Adaptation of an advanced ride dynamics computer program for analysis of the capabilities of an unconventional vehicle
- Adaptation of a similarly advanced soft soil performance model to CTVSD analysis
- Development of a simplified blast effects computer model
- Application of these models in parametric analyses to provide input to the design process
- Completion of preliminary design investigations to resolve problems in the input design concept
- Completion of analytical/design tradeoff studies to define design approaches to an optimal CTVSD vehicle
- Definition of a potentially viable CTVSD baseline concept
- Detail design of a single suspension quadrant test rig
- Identification of a series of promising special devices for energy management

It was originally anticipated that mobility would be a significant design constraint and that blast resistance would be limited. Expendability of individual suspension station components was expected upon mine detonation. During August 73 it became clear that ride-limited speed capabilities could be provided to allow CTVSD to operate with current M60 tanks, or even

the faster product-improved tanks currently in development. The reason for this result is that the disadvantage of high unsprung weight (heavy road-wheels) is more than offset by advantages in all other parameters related to ride. Advantageous comparisons of CTVSD to M60A1 include:

- Lower spring rate
- More shock absorbers
- Increased jounce travel
- Increased track length
- Lower CG

This finding permitted the design to be optimized for blast resistance to a greater degree than originally anticipated. We proceeded in an iterative process to develop a "balanced" suspension system design having a composite component safety factor of 1.5 for various track/mine geometrical relationships. If the 100,000 ft-lb energy value and blast impulse time assumptions are valid, the system will be capable of continued mine-clearing operation after one or more detonations. The calculations indicate that the spring, roadarm, axle, bearings, and hub will survive the specified blast without damage and other components can be replaced in the field to restore the vehicle to original mobility levels.

Damage expectations are summarized as follows:

- Track will fail, as assumed by MERDC (see paragraph 2.3)
- Roadwheel rubber tire will fail, although the failure will not preclude continued operation
- Individual roadwheel rim sections may fail in a mode probably permitting continued operation
- Automotive-type shock absorbers will fail, but also in a mode allowing continued operation

The only exception to this encouraging view of system blast resistance is that the current suspension bracket structure is not adequate for extreme offset blast conditions. The solution to this problem lies in integration of the suspension support and hull structures.

This forecast of mobility and blast resistance capability is considered encouraging in regard to the viability of CTVSD as a candidate mine-clear-

ing system and the following recommendations are presented for further development:

- Continue investigation of promising special energy management devices
- Continue refinement of the blast effects model, using finite element techniques
- Initiate structural integration studies
- Procure test rig hardware
- Conduct first-generation tests on the test rig suspension quadrant

First priority should be given to hardware tests. Analytical and design investigations should be considered secondary.

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3.0 ANALYTICAL DEVELOPMENT

The operational role of the Combat Tracked Vehicle Signature Duplicator (CTVSD) requires it to accompany the lead units of an advancing armor column. It should be capable of speed at least equal to that of the column when approaching a mined area, as well as capable of maintaining headway after multiple mine detonations, to complete the mission of clearing a safe route of advance for the following combat vehicles. These capabilities should be operative in a wide variety of terrains without inversions in relative performance of the CTVSD and associated armor units. CDE has determined the functional characteristics of a suspension system to achieve the mobility performance goals and has suggested and evaluated means for attenuating blast energy transmitted to the hull of the vehicle.

Mobility activities began with extensive modifications to existing computer models for accommodation of the CTVSD configuration. The ride dynamics model was then used to determine the limiting speed of an undamaged CTVSD, as controlled by driver reaction to vibrations imposed by terrain roughness. Four real and two artificial terrains were used in the course of deriving suspension characteristics necessary for the CTVSD to equal or exceed ride-limited speeds for current and future tanks. Ride dynamics analyses were conducted in close liaison with the design group to insure the practicability of suspension recommendations.

Soft soil mobility of the evolving CTVSD design was also evaluated by computer simulation, using an expanded version of the basic CDE STEERMOD program. In addition to accommodating the distinctive geometry of the vehicle, the model also accounted for engine, transmission, and steering system performance, motion resistance peculiar to unpowered rigid wheels, and all important combinations of blast-damaged suspension geometry, all on selected soils and slopes. Of 23 possible blast-damaged configurations, there are 14 unique combinations of missing tracks or roadwheels (nine are symmetrically opposite). All were examined, along with the undamaged vehicle, for a no-go or go speeds for a range of soils and slopes. This model can be used subsequently to balance power train with suspension characteristics.

The mobility analysis has demonstrated that basic CTVSD performance goals can be achieved within the constraints of feasible suspension hardware. It has also proven to be possible to devote considerable attention to blast resistant configurations without unacceptable penalties in cross-country speed.

In an action intended to minimize structural damage from mine blasts, a special computer model was written to evaluate various methods of reducing shock energy transmitted through suspension elements to the hull. Shock absorber and roadwheel bump stop characteristics were studied with this model, along with roadwheel and roadarm weights. It has been determined that considerable deviation from the optimum suspension can be tolerated to increase the blast survivability of suspension components. With this confi-

dence in ability to achieve speed targets with reasonable freedom in design, it was possible to devote more attention than anticipated to design for blast resistance. Investigation of materials, components, and geometries in the suspension area show promise of producing increased survivability of roadwheel and roadarm assemblies.

Suspension structures were designed by application of conventional stress analysis techniques, using data from the blast effects model and established design factors for other load inputs. The objective was to define a balanced design, with a uniform set of safety factors in all components for the various blast and other load inputs. The analysis indicates that the suspension system will survive specified blast inputs without loss of capability for continued operation, although track and other elements in the near field of the blast will require later replacement to restore full mobility capability. Further test data is required to validate this analytical result.

3.1 RIDE DYNAMICS INVESTIGATIONS

3.1.1 Objectives

The major objective of the ride dynamics investigations was to assure that the vehicle to be developed would have a cross-country speed capability equal to or exceeding that of presently operational and development tanks. The effects of variation of suspension parameters, such as spring rates, damping rates, and wheel weights, were analyzed to approach an optimum vehicle design from a ride dynamics standpoint. The ride characteristics of the M60A1 and the M60A1PI (Product Improved) tanks were used for comparison purposes.

3.1.2 Model Description

3.1.2.1 Original Model

Chrysler has in its computer program library an operational ride dynamics model. This model had been developed to investigate the ride dynamics of tanks and other tracked vehicles and has been used extensively in the M60 series tank and other analyses. It is an eight-degree-of-freedom, nonlinear, two-dimensional (bounce and pitch) model, which simulates hull bounce and pitch and angular wrapup of roadarms as the vehicle traverses selected terrains. This model integrates the dynamic equations of motion at time increments and produces results in the form of time histories. The model takes into account nonlinear and torsional characteristics of the springs and dampers and considers bump stop and track effects. It allows for the wheels to leave the ground, and roadwheels are constrained in rebound by the track.

3.1.2.2 CTVSD Model

It was decided that the most efficient method of developing a dynamic computer ride model for the CTVSD would be to modify the existing model. Several adjustments were needed to conform with the peculiarities of the CTVSD vehicle configuration. These included:

- Track influences were modified to account for the two separate sections on each side. Each section was modeled separately, allowing for the different number of roadwheels included in each section.

- The subroutine which computes the terrain input to the wheels was changed to account for the number of wheels and wheel spacings.

- The main program was modified to account for the five wheels of the CTVSD, rather than the six wheels of the M60.

- Two track sections per side require two sprockets and two idlers, rather than one of each. The track tension effect causes four force inputs per side to the hull, rather than two as with the standard tank configuration. Similarly, there are now four corner wheels per side, rather than two, for which the track tension effect was taken into account.

- In previous models, the total angular wrapup for the spring from free position to bump stop position was determined by stress limitations on the spring and was constant for all positions. However, when dealing with the torsilastic springs on the CTVSD, the limiting consideration is that of space, rather than stress limitations. Therefore, jounce travel is constant at all positions, which in general causes different total angular wrapup at all positions. Changes were made in the program to account for this.

- Consideration was given to placing the mobility bump stop below the torsilastic spring, rather than on the hull above the roadwheel. An alternative suggestion was to attach volute or similar springs to slow the wheel before hitting the bump stop. The reactions at the hull and the roadarms change for both alternatives and required computer modifications.

3.1.2.3 Model Parameters

The computer model allows for parametric runs to study the effect of variation of parameters of interest. The following parameters were varied to

find their optimum characteristics within the physical constraints of the system:

- The torsilastic spring rate (jounce travel can be varied, but was not changed for this analysis).
- The shock absorber damping curve, including the rate and blow-off level in both jounce and rebound
- A study of which positions should include shocks was made (shocks at all positions vs. positions #1 and #5 only).
- Roadwheel weight
- The spring and damping rates of the bump stop. Also, the effect of changing the location of the bump stop was investigated, both in effect on ride quality and on forces in the system.

Interdependency of these variables was allowed for in the parametric studies.

The vehicle model was run over a mathematically synthesized random terrain, with the amplitude factor changed from run to run to produce different RMS roughnesses. The random terrain was preferred to actual terrains, because these tend to have inherent periodicities. The computer model for the final optimum configuration was subsequently run over familiar terrains from Fort Knox and Aberdeen Proving Grounds.

The major quantitative factor used in the evaluation and comparison of parametric computer runs was the driver's absorbed power, which is considered the best mathematical indication of ride quality and an absorbed power of six watts was used as the maximum level that the vehicle crew can accept without performance degradation or the possiblity of physical harm. The speed at which six watts of driver absorbed power is produced is defined as the V-ride speed. Other statistical quantities such as RMS acceleration at the driver's position, RMS acceleration at the C.G. and RMS pitch, pitch velocity, and pitch acceleration were also considered.

3.1.3 Study Results and Evaluation

The ride dynamics investigations were the critical activities early in the project. This element of the total studies produced design parameters for suspension elements that would permit the CTVSD to have a ride-limited speed equal to, or greater than, the M60A1PI. The concept for deployment of the CTVSD places it near the lead of an advance column of main battle tanks and it is desirable that its speed of advance not inhibit that of the column. Ride dynamics are critical only for an undamaged vehicle and no investigations were made of the ride quality of damaged vehicles.

The ride dynamics study involved an interaction between the estimates of suspension characteristics and available components that were desirable for a simple, rugged design. The results of these investigations are shown in table X which lists ride-limited speed comparisons of the CTVSD, the M60A1 and the M60A1PI. Six terrains are listed that cover a broad spectrum of off-road conditions. It will be noted that in all cases the CTVSD is able to equal or exceed the speeds of the tanks used for comparison. No single factor accounts for the better performance of the CTVSD, but comparison of suspension characteristics on table XI reveals that higher jounce, adequate damping, and different resonant frequencies combined to produce this desirable result. Adequate power to achieve these speeds is assumed in all cases.

TABLE X. COMPARISON OF RIDE-LIMITED SPEEDS, MPH

TERRAIN	CTVSD PRELIM	M60A1	M60A1-PI
Random 3" RMS	25-30	14	21
Random 5" RMS	9	6	8
Rocky (Ft. Knox)	14	2.5	12
Mild (Ft. Knox)	30-35	20	21
Medium (Ft. Knox)	25-30	14.5	16
Perryman (APG)	9	4.5	6.5

TABLE XI. SUSPENSION CHARACTERISTIC COMPARISON

SPECIFICATION	CTVSD PRELIM	M60A1	M60A1-PI
Wheel Spring Rate lb/in	831	1645	1185
Jounce Travel, in	10	7	10.5
Shock Absorber: Type	Linear	Linear	Rotary
Positions:	All	1, 2 & 6	1, 2 & 6
Pitch Natural Frequency, Hz	1.14	1.02	0.86
Bounce Natural Frequency, Hz	1.16	1.40	1.20

An early investigation of torsilastic springs revealed that a wide range of spring rates could be used within the constraints of the design envelope. Spring rates were selected based on experience with previous vehicle designs and varied to arrive at an optimum value (figure 2). It was determined that a spring rate of 300,000 in lb/ rad produced the best ride value for absorbed power at the driver's location.

In these investigations, trends in driver absorbed power were used to guide selections of suspension parameters. An absorbed power level of 6 watts is the accepted limit for sustained human exposure to vibrations. Rather than running a spectrum of speeds to define the V-ride speed (speed at which driver absorbed power just equals 6 watts), examination of absorbed power trends effected time savings in the analysis. This technique permitted the investigation of a larger number of variables at more levels than would otherwise have been possible.

An investigation was also made to determine where shock absorbers should be located. As illustrated in figure 2, shock absorbers at all locations proved better than location on the corner spring elements, although the V-ride target could be achieved with only four shock absorbers. Damping rates of the shock absorbers were also investigated to determine an optimum value. Both driver absorbed power and RMS acceleration at the driver position were used as evaluation criteria (figure 3). A damping rate of 350 lb-sec/rad proved to be the desirable level with minimum values for both criteria associated with this level. An associated study of blow-off levels for the shock absorbers was also conducted and a value of 3,500 lb was selected as optimum.

The weight of roadwheels was a matter of some concern. Heavy roadwheels are desirable for blast resistance for two reasons. Heavier roadwheels will have greater structural integrity and a heavy roadwheel will also absorb more blast energy and transfer less energy to the hull. Heavy roadwheels have the disadvantage of increasing unsprung weight and thereby contribute to higher absorbed power and reduced cross-country speed. Figure 4 illustrates the effect of roadwheel weight on absorbed power as the weight is varied from 200 to 1,000 lb per position. This weight includes two roadwheels, wheel/arm interface hardware, and one half the roadarm weight. The expected trend is shown, but the increase in absorbed power is less than might be expected. This is attributed to the relatively small change in the ratio of sprung to unsprung mass. A value of 800 lb per station was recommended as a reasonable design departure point, since it incorporates two of the specified 300 lb roadwheel rim sections. Later optimization studies may show that increased roadwheel weight would optimize concept characteristics.

A reassessment of the many elements of the ride dynamics study was made in order to identify desired levels of suspension design parameters and ranges through which these values could be varied in response to detailed design needs. Table XII presents the recommendations. The significant feature of the parameter array is the design latitude afforded. It has been determined

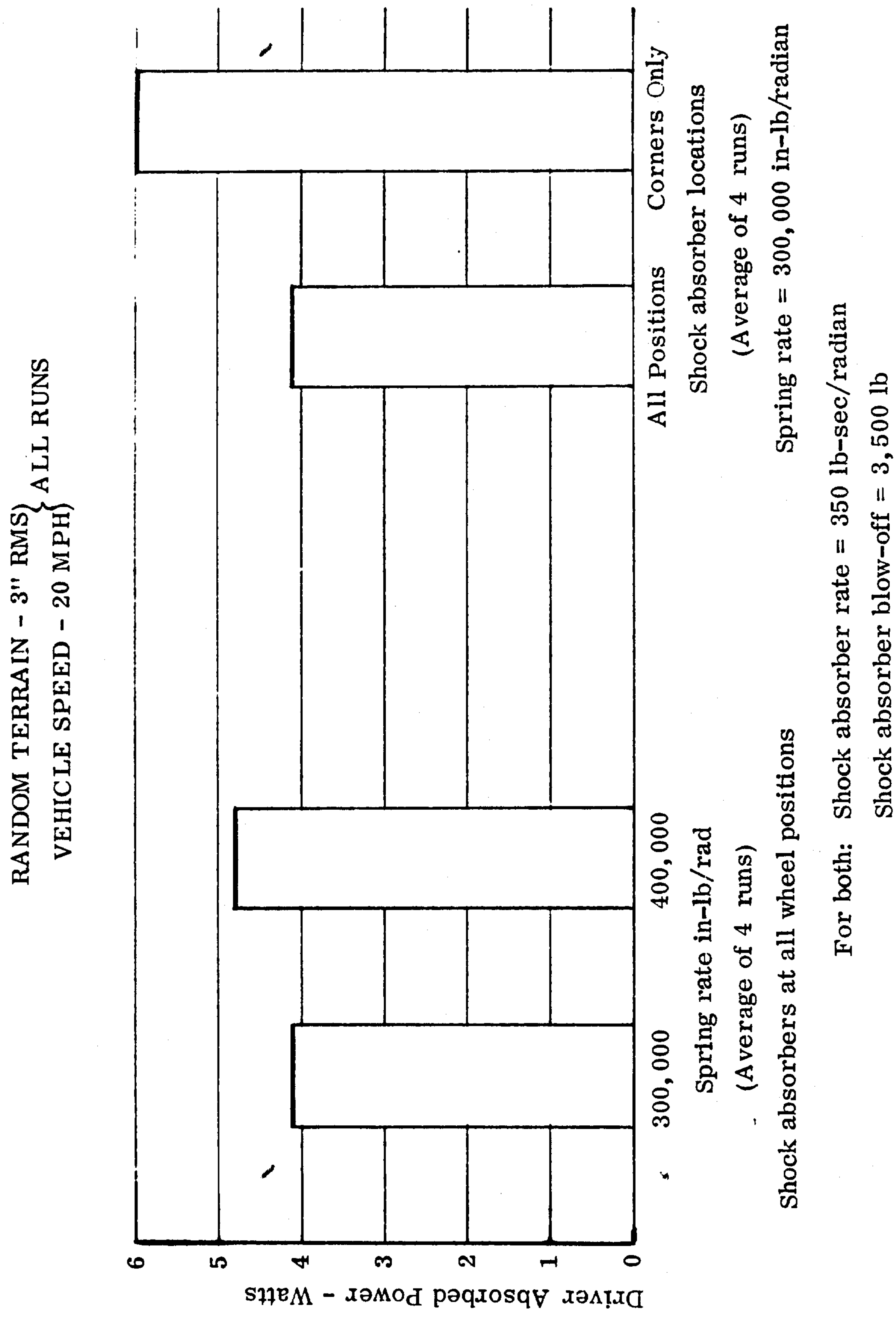


Figure 2. Spring Rate and Shock Absorber Location

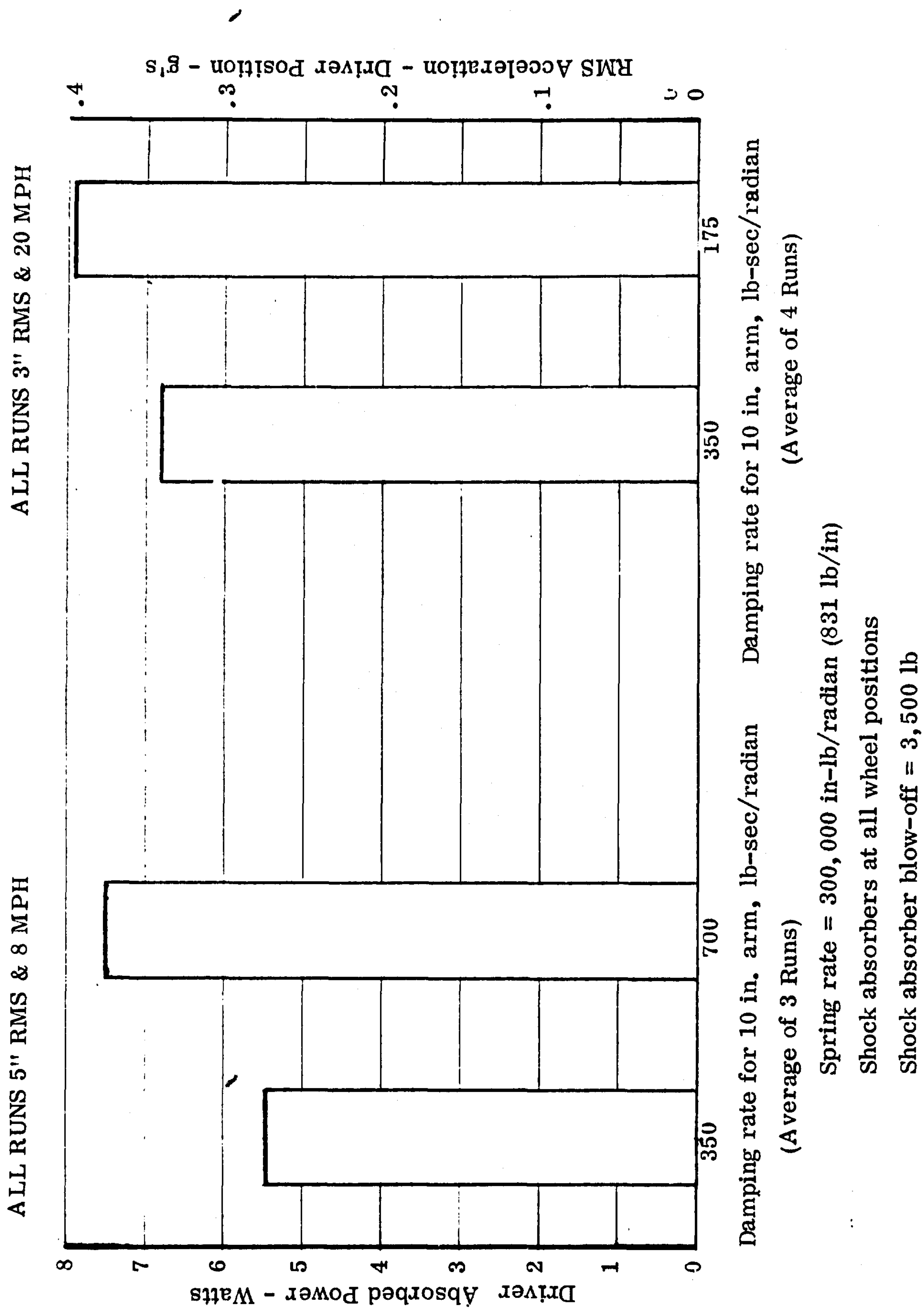


Figure 3. Shock Absorber Damping Rates

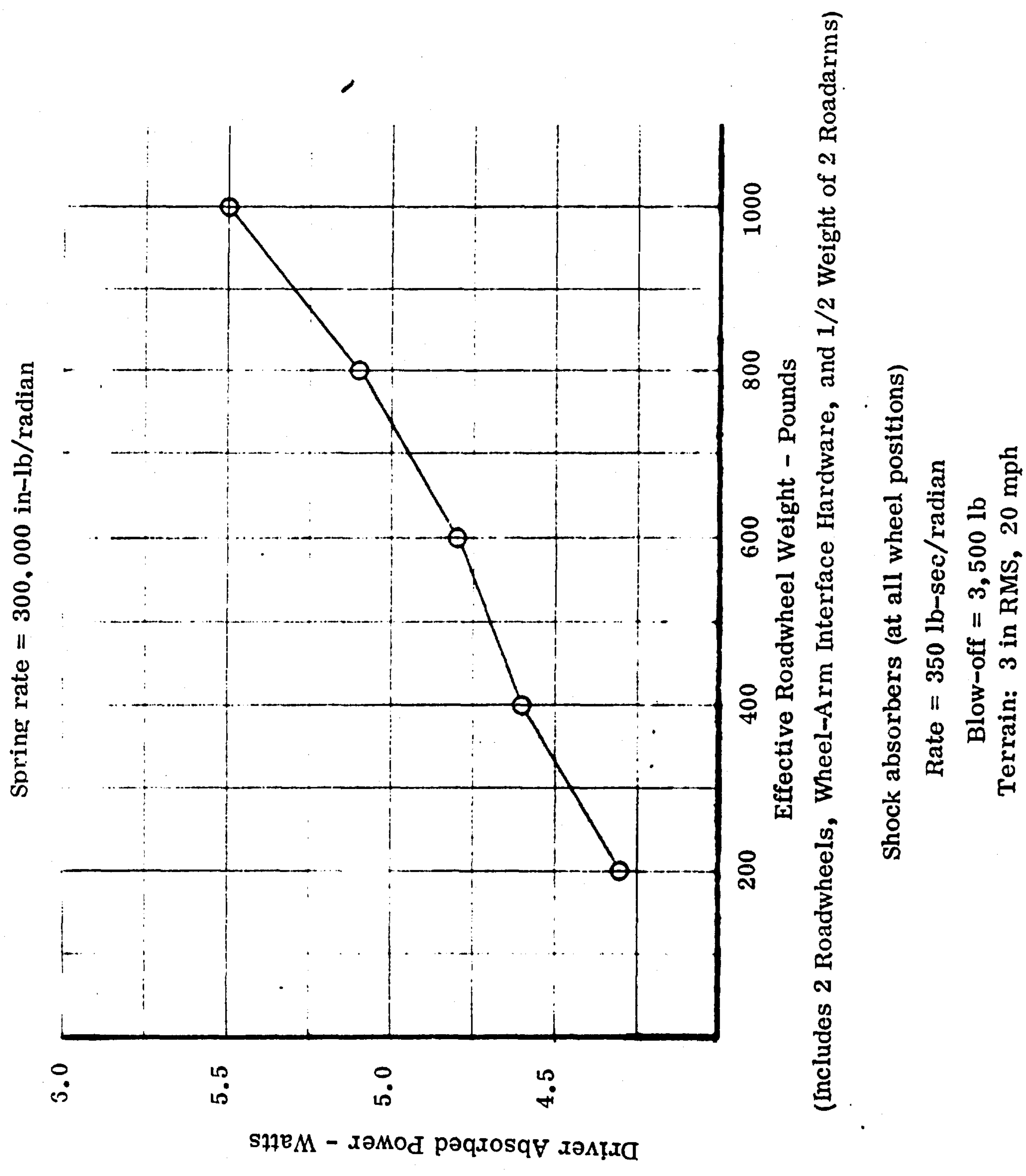


Figure 4. Roadwheel Weight Variation

TABLE XII. RIDE DYNAMICS DESIGN RECOMMENDATIONS

Parameter	Recom'd Level	Acceptable Range
Spring Rate, in-lb/rad	300,000	300,000 - 400,000
Shock absorbers at wheel positions:	All	Corners
Damping curve: rate, lb-sec/in	350	250-600
blowoff-in jounce, lb	3,500	2,500-6,000
Roadwheel weight including 1/2 of roadarm, lb	Low as possible	1,000 max.
Mobility bump stop, lb:in	20,000:3	Not checked
Jounce travel, in	10	≥ 10
Gross vehicle weight, lb	70,000	As low as possible

that requisite suspension parameters offer no undue constraints on hardware design. Because of the design flexibility possible within these ranges, factors driving design were then related to the blast resistance criterion. Judgment has been exercised during the design to prevent a stacking of suspension parameters toward the least desirable end of the various ranges listed.

The initial questions regarding the ability to design a CTVSD suspension to make it compatible with M60 series tanks have been answered affirmatively from a ride dynamics point of view. It will be possible to achieve driver limited speeds of the order of those associated with the product improved M60 over a wide variety of off-road terrains. Adequate horsepower to achieve these speeds has been assumed throughout this analysis.

It has been determined that requisite suspension parameters offer no undue constraints on hardware design. Latitude in design selections from ride dynamics considerations permitted design efforts to be focused largely upon blast resistance.

3.1.4 Conclusions

The ride dynamics study has produced four major conclusions:

- The CTVSD can maintain lead position in a column of M60A1-PI tanks.
- The demands placed on suspension design are reasonable.
- The design latitude afforded by acceptable ranges of suspension parameters has permitted attention to special requirements for blast resistance.
- Based on recommended levels for CTVSD suspension design, the CTVSD can match the M60A1-PI speeds over any of the six terrains used in this analysis, and these terrains are sufficient to cover all terrains of major importance.

3.1.5 Recommendations for Design

Recommended levels of suspension design parameters are presented in table VIII.

3.2 SOFT SOIL INVESTIGATIONS

3.2.1 Objectives

The objectives of the soft soil mobility investigations were:

- To provide quantitative mobility performance characteristics of a selected baseline CTVSD vehicle for comparison with the M60A1 tank
- To delineate the limiting mobility characteristics of undamaged and various specified blast damaged configurations of the CTVSD
- To determine vehicle design approaches that will improve CTVSD mission capability

3.2.2 Model Description and CTVSD Inputs

Soft soil performance was simulated by the CDE STEERMOD program, which analyzes the vehicle-ground interaction of a tracked vehicle in a steady-state situation, taking into account differential speed of the tracks. Soft soils are described in terms of Bekker parameters. Sinkage and resistance to forward motion are computed independently for the two sides of the vehicle. The program uses fore and aft and lateral force balance equations, with roll and yaw moment equations as a basis. Differential track speed results from track slippage incurred in an attempt to drive the vehicle in a straight line with unequal drag forces on the two sides of the vehicle. Substantial program modifications were required to accommodate the segmented track and the presence of unpowered rigid wheels in the various CTVSD damaged configurations. The damage configurations were designated as follows:

Two tracks removed

	wheels intact	one wheel removed	two wheels removed
Both front quadrants	A1	B1	C1
Both back quandrants	A2	B2	C2
Left front, right back	A3	B3	C3
Right front, left back	A4	B4	C4

One track removed

	wheels intact	one wheel removed	two wheels removed
Left front	D1	E1	F1
Right front	D2	E2	F2
Left back	D3	E3	F3
Right back	D4	E4	F4

A total of 25 configurations were evaluated, including the undamaged case for comparison. Nine of these cases were not considered because of symmetry and C1 may be disregarded, since with both front quadrants completely missing, the vehicle is unstable and will tilt forward on the front of the hull and become immobile.

The program assumes uniform loading over a quadrant. If a track section is missing, the quadrant is relieved of the track weight and the balance of the loading is divided equally among the unpowered roadwheels that remain. In the four cases (C3, C4, F1, F2) where one front quadrant is entirely missing, the diagonally opposite quadrant is assumed to be relieved of loading. The two opposite diagonal quadrants share the entire load.

Steering model inputs are in five categories:

1 Bekker soft soil constants

2 Longitudinal and lateral slope angles

3 Vehicle weight and dimensions

4 A constant representing suspension power loss

5 Engine and power train tabular data

Category 5 above includes the following tables:

- Full throttle sprocket force at pitch radius in lbs, versus track speed in mph
- Towing resistance in lbs, versus speed in mph
- Driver limited speed versus soil characteristics
- Steering loss in hp/mph, versus turning radius in feet
- Maximum steering ratios versus speed in mph at gear shift points

Model outputs consist of:

- Limiting speed in mph, with a code indicating the limiting factor, one of the eight following:

  Imminent overturning | Driver ride tolerance

  Power limitation | Surface traction (excessive slip)

  Skidding | Governor limitation

  Transmission | Hull bottoming

- Soft soil performance numbers such as:

  Ground pressure | Slippage for both tracks

  Sinkage | Nominal turning radius

  Soil resistance to forward motion | Gross traction

- Program variables for diagnostic purposes

These are evaluated for all soils, longitudinal slopes, and lateral slopes that were included in the inputs and repeated for as many damage configurations as specified. Computation is made in increments of 0.5 mph until a limitation is exceeded. At this point, speed at the limitation is determined by interpolation within the last speed increment and performance numbers are then evaluated at the actual limiting speed.

The following modifications of the basic model were necessary to adapt the program to the requirements of the CTVSD project:

- Description included the various damaged configurations to be examined
- Coding added to allow treatment of individual quadrants for any damaged configuration
- Program revised to compute normal loading, sinkage, drag forces, etc. independently by quadrant
- Ability to compute soft soil performance of combined track and unpowered rigid wheels has been incorporated.

3.2.3 Soil Parameter Selection

In its original form, the soft soil mobility model used Bekker soil strength parameters. The model was altered to accommodate unpowered rigid wheels and this required that soil strength also be stated in cone index terms. Soil resistance to penetration by a cone penetrometer can be approximated with Bekker soil parameters by:

$$RCI = \left(\frac{kc}{0.796} + k\phi\right) z^n$$

RCI = rating cone index, psi

z = sinkage, in.

kc = cohesive modulus of deformation

$k\phi$ = frictional modulus of deformation

n = sinkage exponent

The analysis requires that RCI be stated as an average for a layer of soil whose depth varies with the minimum width of the ground contact area (RCI_z). For uniformity in comparisons, the soil strength is specified for a fixed depth (in this case the 6" - 12" average RCI, or RCI_9), and the variable layer value is derived from this value for internal use in the program.

We were interested in the soils of West Germany, since this is a theatre of some importance in tank operations. Available soil strength distributions for West Germany are stated in terms of RCI; therefore, it was necessary first to identify important RCI values, and then find Bekker soil values which corresponded. The three selected soils are intended to portray the range of soil conditions which the CTVSD might be expected to encounter. The softest soil selected, (RCI_9 = 77) represents a soil slightly above the minimum soil strength to sustain 50 passes of the CTVSD and also represents a soil strength that is near the minimum found in wet season West German soils. Bekker's work presents soil parameters for a soil with RCI_9 calculated to be 77 and therefore this compatible set of soil parameters was used in the program. The 50-pass criterion for soil strength was used rather than one-pass since the CTVSD is envisioned as leading a column of tanks whose soft soil mobility is of the same order. Route selection by the CTVSD would thus be limited to those areas capable of withstanding the stresses of the trailing tank column. The mid range value of RCI_9 = 158 represents a minimum soil strength for the "average" season West German soil as well as a substantial percentage (about 60 percent) of wet season soils as shown in table XIII. Since the RCI_9 = 158 soil is a minimum value for all West German soil conditions, except for about 40 percent of the wet season conditions, it was used as the baseline condition.

The soil with RCI_9 = 668 roughly corresponds to a secondary road or dry, hard, off-road soils.

Table XIII also contains useful information on the distribution of slopes for these terrains. It can be seen that some 83 percent of the terrain is at slopes of 15 percent or less, indicating the desirability of maintaining operational capability for a damaged vehicle on slopes up to at least 10 percent. It should be noted that the softer soils will not, in general, be found on the steeper slopes.

3.2.4 Results and Evaluation

The print-outs of the soft soil program are very extensive and include the values of all the input parameters and the resulting parameters that determine the vehicle speed. Each print-out covers seven values of soil strength (RCI_9 = 77 to 668), three slope levels (0 percent, 5 percent, 10 percent) and two horsepower levels (450, 600) for the undamaged vehicle and the fourteen damaged configurations. The results for the initial CTVSD concept are summarized in table XIV. Data is presented for the RCI_9 = 158 soil considered to be the best "design-to" terrain for a mine-clearing environment and also for a soil with RCI_9 = 77, considered the lowest strength in which mine-clearing would be feasible. Results are for zero slope and with the 450 HP engine. In this table, a dot (●) represents a missing suspension station, a (o) a damaged station with the track gone and the wheel remaining in place, and the symbol (ↀ) indicates that the quadrant remains intact.

TABLE XIII DISTRIBUTIONS OF TERRAIN CHARACTERISTICS

NOTE: Measured from a portion of West German transect (481 terrain units)

a. Surface Type Distribution

RCI_9 PSI	Dry	Average	Wet
	(% of Total Distance)		
580	100	100	100
480	3.29	79.21	100
370	3.23	42.01	100
250	0	40.93	100
150	0	3.23	42.01
100	0	3.23	40.93
70	0	0	3.23

b. Slope Distribution

% Slope	% Of Total Distance
1	1.75
3.5	28.26
7.5	27.89
15	24.83
30	13.68
50	3.42
65	0.17

TABLE XIV SUMMARY OF MOBILITY IN DEGRADED MODES

CONFIGURATION DESCRIPTION		NO.	CTVSD SPEED, MPH* RCI $_9$ SOIL STRENGTH	
RIGHT	LEFT		77	158
ꝏ ꝏo	. o ꝏo	E1-2	0	0
ꝏ . oo	. o ꝏo	B3-4	0	0
. o ꝏo	. o ꝏo	B1	0	0
ꝏ ꝏo	ꝏ . . o	F3-4	0	2.45
ꝏ . . o	ꝏ . . o	C2	0	3.79
ꝏ ooo	oo ꝏo	A3-4	0	1.12
ꝏ ꝏo	oo ꝏo	D1-2	0	.40
oo ꝏo	oo ꝏo	A1	0	2.23
ꝏ ꝏo	ꝏ . oo	E3-4	2.61	5.18
ꝏ . . o	. . ꝏo	C3-4	10.16	16.07
ꝏ ꝏo	ꝏ ooo	D3-4	3.83	6.11
ꝏ ꝏo	. . ꝏo	F1-2	10.82	16.34
ꝏ . oo	ꝏ . oo	B2	4.08	6.27
ꝏ ooo	ꝏ ooo	A2	5.21	8.03
ꝏ ꝏo	ꝏ ꝏo	OK	17.68	23.21

• Wheel Missing
oo Track Missing
ꝏ Quadrant Intact
*** Preliminary CTVSD configuration with 450 hp on level ground**

In a further effort to present a meaningful mobility comparison and evaluation between the undamaged vehicle (Configuration OK) and the various damaged conditions, a baseline set of conditions have been selected for presentation. The baseline CTVSD mobility condition is selected at a 0 percent slope, (level ground), with 450 HP, and on a soil strength of $RCI_9 = 158$.

From figure 5 it is evident that damaged vehicles F1 and C3 are only 7 MPH slower than the baseline OK configuration. These configurations are essentially identical since they depict the case wherein one front quadrant is missing and the diagonally opposite quadrant is assumed to be relieved of loading, while the remaining two diagonal quadrants share the entire load. Since only tracked quadrants are presumed in ground contact, the traction is high, sinkage and slip are low, with resulting low drag. Only four damaged configurations are immobilized at zero slope on this soil.

3.2.5 Evaluation Summary

The undamaged 450 HP CTVSD mobility on level ground is compatible with the M60A1 tank on all soils with greater differences in the softer soils. See figure 24. The CTVSD speed is 12 percent less than the M60A1 on the soil $RCI_9 = 158$, and improves to 9 percent less speed than the M60A1 at $RCI_9 = 668$. The slope mobility of the 450 HP undamaged CTVSD is nearly identifical to the M60A1 at the softer soils. The CTVSD loses 42 percent of its baseline speed at a 5 percent slope and 54 percent at a 10 percent slope.

Increasing the CTVSD HP to 600 will produce a baseline undamaged CTVSD that will exceed the M60A1 tank at all soil conditions except the very softest $RCI_9 = 77$, at which point on level ground it is only 3 mph slower.

The conclusions concerning the mobility of a blast damaged CTVSD are highly dependent on which quadrant is damaged and on the extent of damage. The overriding cause of mobility degradation is the loss of tracks, leaving unpowered roadwheels in contact with the ground. The roadwheels sink and cause a high drag.

The selected vehicle CG location affects mobility since it determines quadrant loading, which in turn determines wheel sinkage. The CG location also is a factor in slope climbing where a quadrant load shift can further increase the wheel sinkage. It appears that a change in CG location to produce more equal roadwheel loading will improve this situation. (This was done in later configuration definition).

Unsymmetrical damage causes further mobility loss because of the power required to keep the vehicle on a straight course. Increasing the horsepower to 600 will help under these conditions. Increased horsepower will only be effective for the CTVSD if the complete power train is optimized for the probable soil condition spectrum expected, considering blast damage conditions.

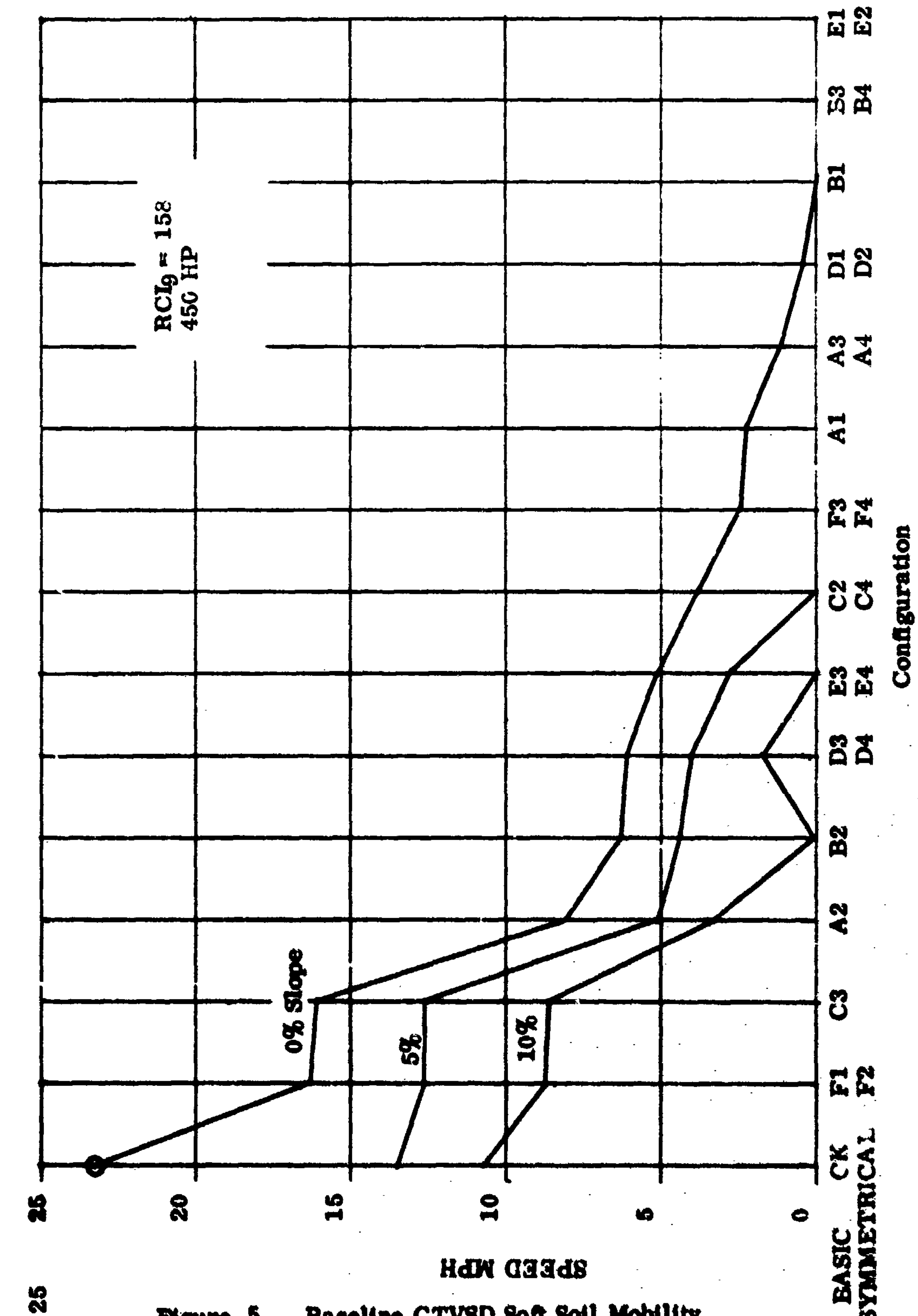


Figure 5. Baseline CTVSD Soft Soil Mobility

In conclusion, all but four of the 14 unique damaged configurations will continue to be mobile under the baseline soil and slope conditions. The four immobile configurations could be made mobile by causing the one remaining wheel in the damaged quadrant to also be removed during the blast. Increased mobility throughout the present damage condition spectrum could be increased by an optimization of the CG location and increased horsepower with an optimized powertrain.

From this evaluation, it is evident that quantitative changes in the baseline design should not be made based on mobility data alone, unless a specific mobility capability is specified for each damaged condition. CTVSD mobility in damaged modes is judged to be good.

3.2.6 Conclusions

- The soft soil performance of the undamaged CTVSD can be compatible with that of the M60A1 tank. Some improvement of performance in the softer soils is required to equal that of the M60A1PI.
- Most CTVSD blast damaged configurations remain mobile in soils of critical interest.
- A rearward shift of the CTVSD center of gravity to produce equal loading on all wheels will improve soft soil performance for both undamaged and damaged configurations.
- Soft soil mobility degradation is related directly to the motion resistance of unpowered rigid wheels and associated loss of traction when a track is lost.
- An increase in horsepower of the CTVSD is needed to increase the speeds of the mobile configurations.

3.2.7 Recommendations for Design

- An evaluation of the mine threat should be made to determine probabilities of occurrence of each CTVSD blast-damaged configuration before comprehensive soft-soil mobility enhancement recommendations are made.
- The center of gravity of the CTVSD should be located such that each roadwheel receives approximately the same loading.
- The engine/transmission characteristics should be optimized specifically for the CTVSD to match M60A1 soft soil performance.

3.3 BLAST EFFECTS ANALYSIS

A critical aspect of the CTVSD system concept is the response of the suspension to mine detonation beneath the track and the resultant transfer of the blast energy to the hull. It is desirable to minimize energy transferred to the hull and to the occupants of the vehicle to prevent damage to the vehicle and to prevent personal injury. It is also necessary to design each suspension unit to be as blast resistant as possible to prevent a unit from becoming inoperable as a result of a mine detonation under an adjacent unit. The analysis of suspension structures exposed to mine detonations is complicated by the fact that extensive and reliable blast effects data are not available. However, general system response characteristics can be determined from analytical techniques as an aid in system design by considering simplified system dynamic response mathematical models.

3.3.1 Objectives

The objective in modeling the CTVSD suspension unit system by dynamic simulation is to determine design parameters that are significantly affected by mine detonation effects and system design characteristics required for survival.

3.3.2 Model Description

A simplified computer model of the CTVSD suspension unit dynamic response to mine detonation has been programmed for a digital computer. Equations of motion for a three degree of freedom representation of a CTVSD suspension unit have been devised and programmed using the Chrysler MIMIC computer simulation.

The blast effects model consists of a roadwheel set, roadarms, and hull masses with associated spring constants and damping constants. A torsilastic spring is included, along with a simplified representation of a shock absorber. The roadwheel and roadarm angular inertia effects are included. Three free body diagrams are the basis from which the equations of motion are derived:

- Roadwheel assembly
- Roadarm
- Hull

3.3.3 Model Limitations

The force and acceleration levels obtained from exercising this blast effects model are conservative and will be higher than those from a model which considers the elastic and plastic deformation properties of the structural members.

It is difficult to model the structural effects of the suspension unit members, particularly the roadwheels. Techniques do exist which could ultimately lead to a more exact definition of the system dynamic response to mine detonation and these will be considered in future studies.

3.3.4 Parametric Study Results

The blast effects model has been operated to obtain preliminary estimates of the dynamic response characteristics of the suspension unit in the vicinity of a mine detonation. Analysis of shock absorber characteristics and bump stop attributes has provided further insight into the blast condition.

3.3.4.1 Effect of Roadarm Weight

The roadarm weight was determined to be a major factor in the magnitude of the force transmitted through the bearings to the axle from the roadwheels. The relative force between the roadwheel and the roadarm (acting on the axle) is predominantly a function of the ratio of the roadwheel mass to the roadarm mass, since the force generated results from the difference in inertia of the two masses. Table XV summarizes the results of a parametric study of the roadarm weight, with forces on the axle and forces on the roadarm torsilastic spring mount included. Results indicate that the roadarm weight/roadwheel weight ratio should be minimized to reduce bearing forces and to reduce axle forces and axle bending moments.

TABLE XV. INFLUENCE OF ROADARM WEIGHT ON AXLE AND SPRING MOUNT

Roadarm Weight (lbs)	386	193	96.5
Maximum Axle Force (lbs)	308,000	165,000	68,200
Maximum Spring Mount Force (lbs)	246,000	131,000	68,000

3.3.4.2 Effect of Shock Absorbers

A simplified approach was taken to the difficult task of simulating the effects of energy absorption by mobility shock absorbers on roadwheel and hull dynamic responses to blast. For this approach, a shock absorber was assumed to produce a resisting force that was purely displacement dependent. Energy removal by the shock absorber was based on the functional characteristic of a shock that produced a linear increase in force from zero to 100,000 pounds in the first inch of roadwheel travel, and for displacements greater than 1 inch, the force was held constant at 100,000 pounds.

The effects of increasing shock absorber travel from static position to the point of rupture are shown in figure 6. Once the shock absorber has ruptured, the energy it has absorbed is shown by the "energy absorbed" curve. Past the point of shock absorber rupture, the roadwheel is still moving upward since the shock absorber has removed only part of kinetic energy of the moving mass. The residual energy is absorbed by the fracture of mobility bump stops and the crush of the energy-absorbing wheel bump stop as depicted in figure 7. The predicted resultant total wheel travel is also shown in the top curve in figure 6.

Figure 8 illustrates the relationship of axle force and maximum hull acceleration as functions of shock absorber stroke as described in the last paragraph. The maximum axle force is measured at maximum upward wheel travel. The hull acceleration was measured at maximum wheel travel. Only the time span from zero (detonation) to the time when the wheel returns to the static position was considered. No analysis was performed on dynamic response after the wheel returned and passed through the static position, since the model is invalid after this point.

The figures show that the axle force and hull maximum accelerations are not significant functions of shock stroke, but vertical wheel travel and energy absorbed are. If an absorber could be designed to have a stroke of approximately 6.5 inches and a constant force of 100,000 pounds (200,000 for two shocks), and to remain intact through the stroke, it would absorb the total energy input from the blast. Special shock absorber devices under investigation may accomplish this.

3.3.4.3 Effect of Roadarm Bump Stops

A bump stop was modeled as shown in the force-displacement curve in figure 7. The area under the curve is the energy absorbed (equal to force times distance crushed). Figure 9 illustrates the increase in energy absorbed by the bump stop if the area of crushable material is increased and the crush pressure remains the same. A significant portion of the 100,000 ft-lbs of energy input could be absorbed before being transmitted to the hull.

3.3.4.4 Special Devices

The blast effects model has been programmed on the MIMIC simulator to provide for the simulation of special devices. These may include liquid springs, frangible materials, friction snubbers, and other devices currently under investigation (see paragraph 4.4). Several of these have significant potential energy absorbing capabilities at much higher levels than standard components. This capability is important if it is found in blast testing that much higher levels of blast impulse than envisioned are encountered.

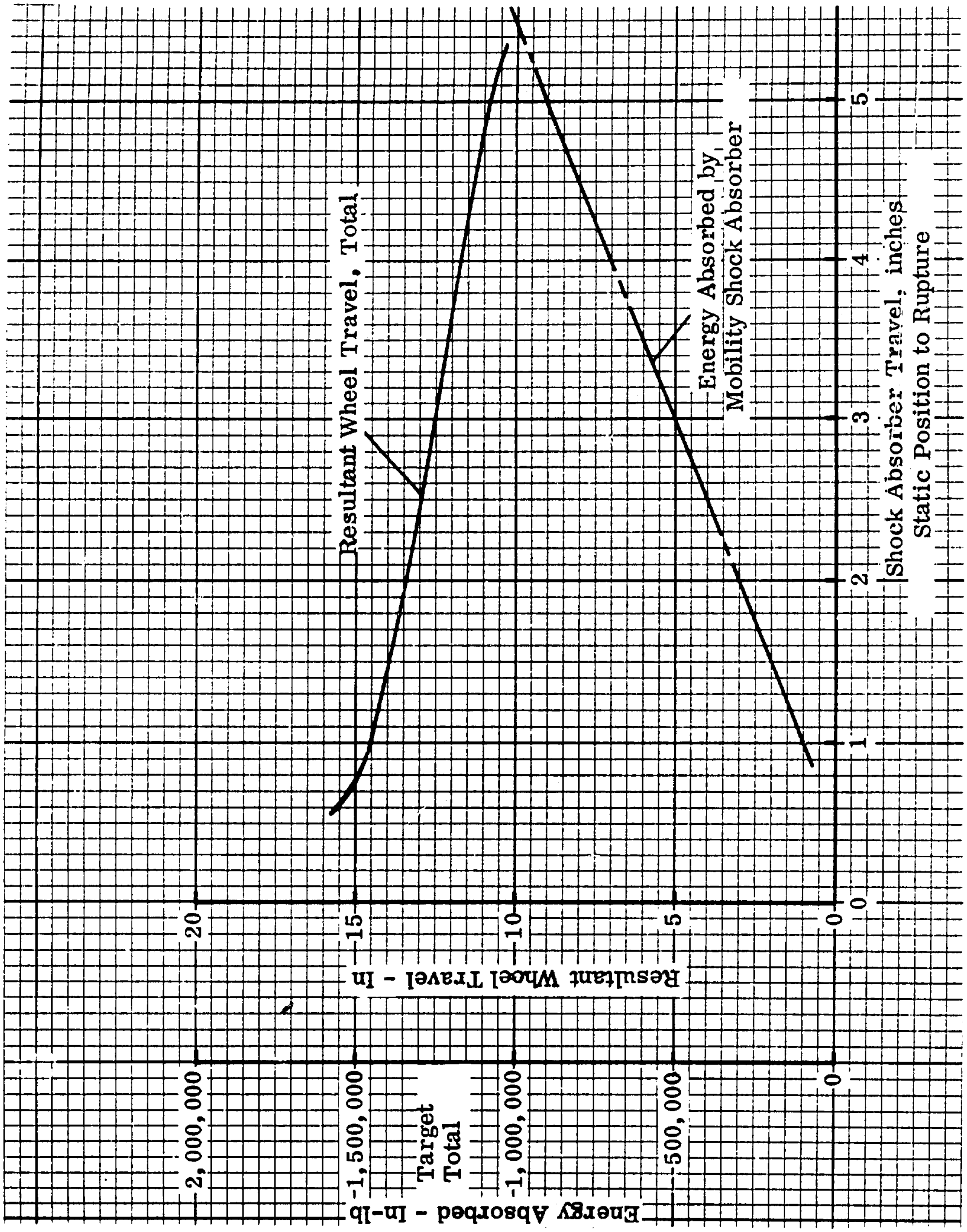


Figure 6. Vertical Wheel Travel and Energy Absorbed

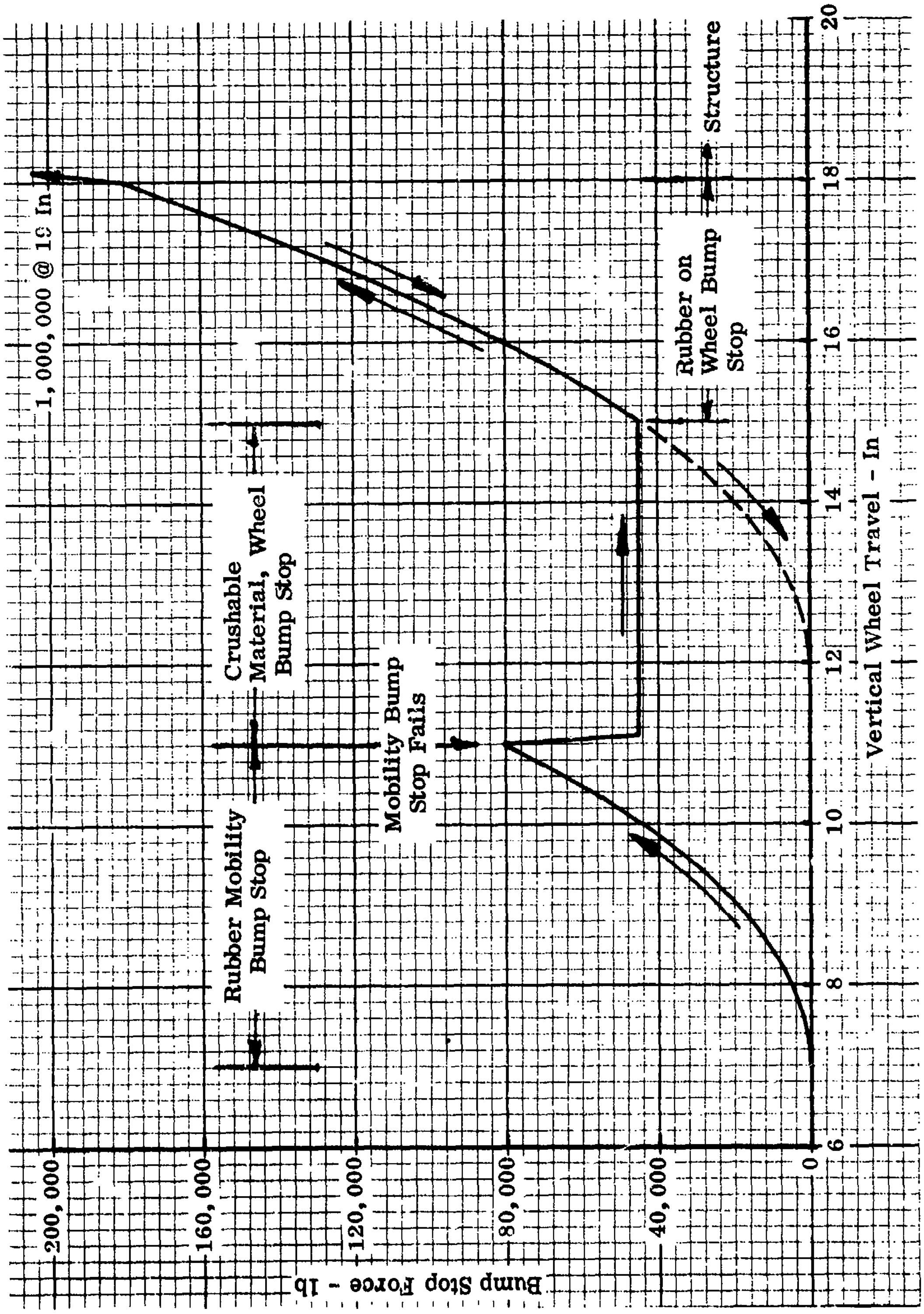


Figure 7. Typical Force - Displacement Bump Stop Function

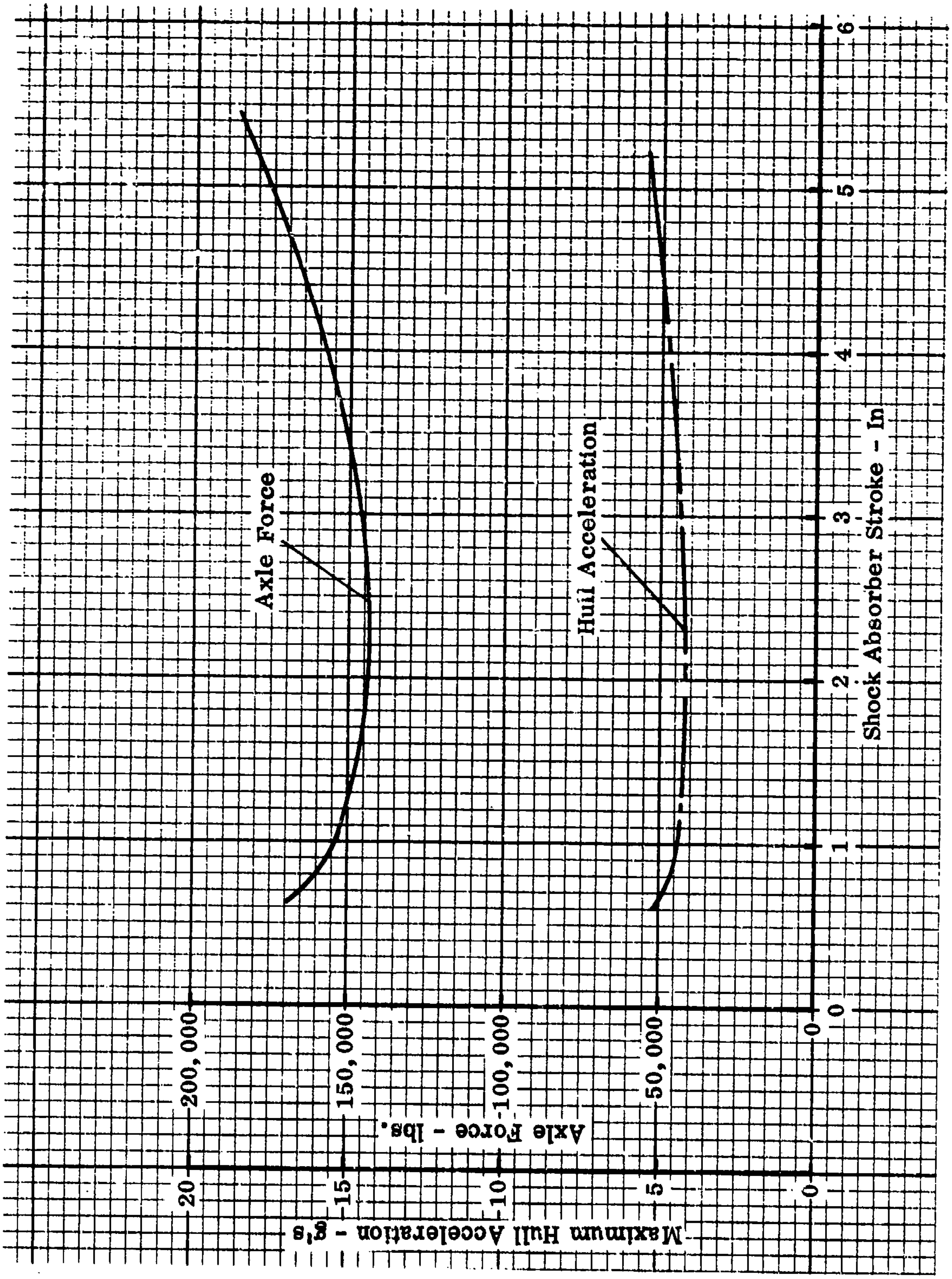


Figure 8. Axle Force & Hull Acceleration

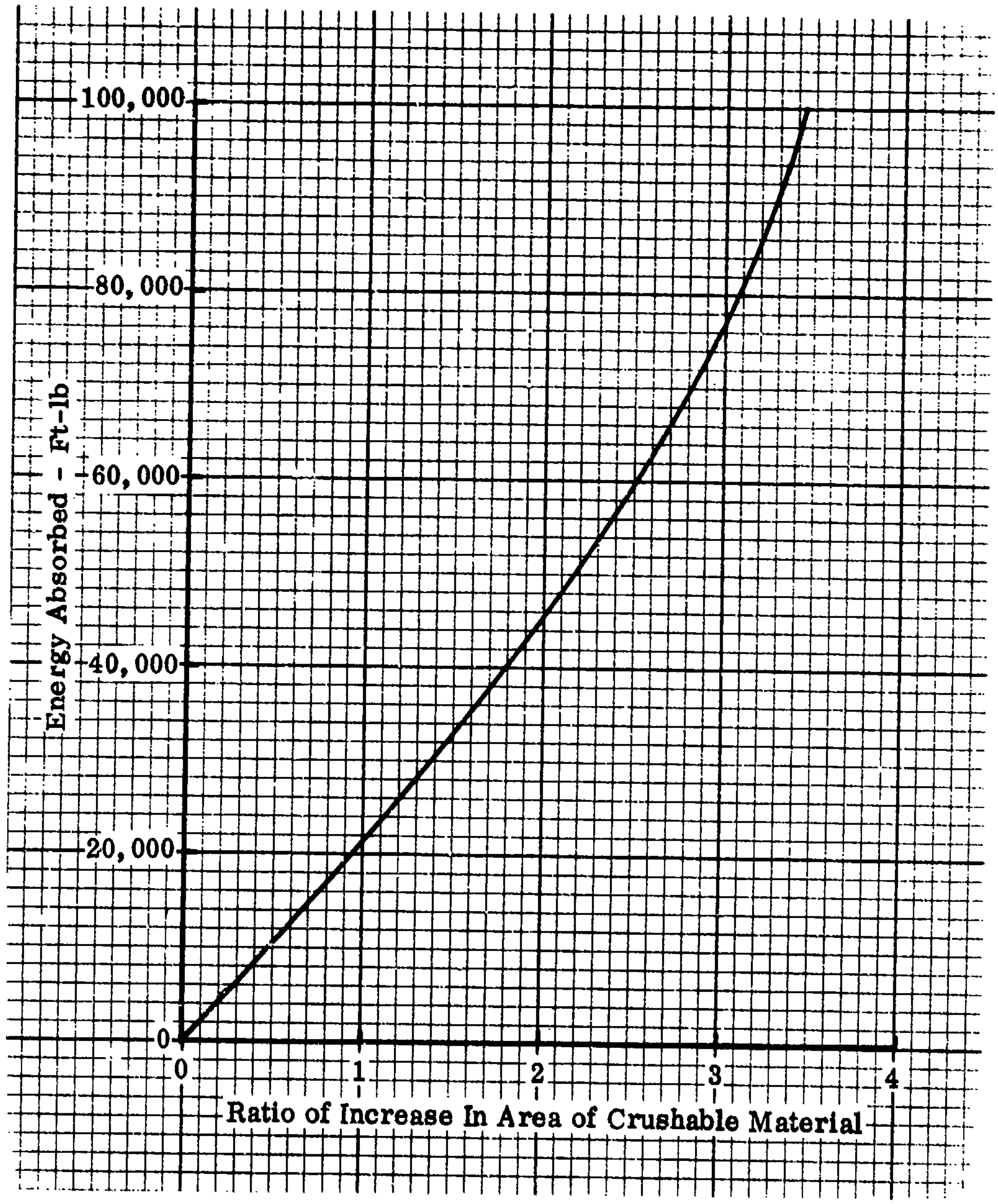


Figure 9. Energy Absorption Increase vs Area Ratio

3.3.5 Conclusions

- The dynamic response of the CTVSD suspension unit can be conservatively determined by a simplified computer simulation model.

- The roadwheel/roadarm weight ratio should be maximized to reduce axle forces.

- Standard mobility-type shock absorbers do not significantly contribute to blast energy absorption. If standard automotive shocks are used, the roadarm and roadwheel bump stops must absorb most of the input energy.

- Special shock absorber devices with high forces acting over long strokes (up to 7 inches) would significantly contribute to blast energy management.

3.3.6 Recommendations

- Validation of the blast effects model by comparison with test results is necessary.

- More complete definition of the suspension unit structural response to high impulse loads is recommended. Particularly, methods of determining structural elastic and plastic deformation need to be considered in future analyses.

- Future simulation models should consider track effects on the suspension system. The impulse delivered to the system through mine detonation acts on the track exposed area, which is considerably larger than the roadwheel exposed area. At the present time, it is not known how the track responds to detonation.

3.4 STRUCTURAL ANALYSIS

3.4.1 Objectives and Approach

Preliminary design analysis of CTVSD suspension and related structure has been performed throughout the design phase to ensure the structural adequacy of design.

The complexity of design, the large number of loading environments, and uncertainties in load assumptions prompted the use of computer aided design techniques for CTVSD analysis. The following specific approach for analysis was planned:

- Development of finite-element computer model of CTVSD hull and

suspension structure. This mathematical simulation was to yield valuable information on redundancy of load paths to and from CTVSD hull, overall deflections, adequacy of fatigue life, optimum distribution of material, and identification of possible problem areas in the complex CTVSD structure.

- Design analysis of individual suspension system components using either finite-element analysis or other conventional methods.

3.4.2 Structural Design Criteria

3.4.2.1 Cross-Country Operation

The following is a summary of structural design loads from the mobility viewpoint. The loads are the equivalent static loads that result from the most severe dynamic conditions the CTVSD is expected to encounter. These loads are used only where more rigorous methods of analysis are not available.

Component	Load and Direction
Wheel Assembly	100% of GVW radially to each dual assembly. 30% GVW radially and 15% laterally applied at wheel O.D. for combined load
Roadarms	10.0 times the average static load supported by each roadarm -- acting vertically
	4.0 times the static load applied vertically combined with 2.0 times the static load applied laterally
Idler Support	175,000 lbs bump load on idler

3.4.2.2 Mine Blast

By contract direction, the blast design loads have been obtained by imparting 100,000 ft-lb of blast energy to the roadwheels of a single suspension station. This energy was specified as that part of the total blast energy remaining after the fracture of the track.

In order to evaluate the forces acting on the roadwheel resulting from this energy, the total impulse had to be determined. The moving mass was assumed to include two roadwheels and half the weight of the associated roadarms and to weigh 800 pounds. The impulse equivalent to the specified 100,000 lb-ft of kinetic energy is 2,250 lb-sec. By further assuming that the force imparted on the structure decays linearly from a maximum at time zero to zero at 2 milliseconds, the maximum force on the roadwheel would be 2,250,000 pounds (figure 10).

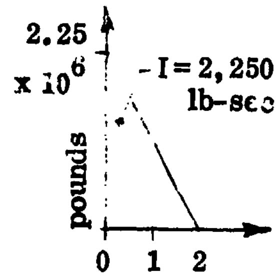


Figure 10. Blast Wave Approximation

The 2 millisecond time was selected to represent typical blast wave time decay and to facilitate mechanization of the program on the MIMIC computer. The incremental integrating interval for MIMIC was 1 millisecond.

In a separate study, an analysis was made of the impulse resulting from detonation of a 20 pound mine at two different locations under an undamaged front suspension station (figure 11). Under these conditions, impulses imparted to the track and roadwheels are as follows: (See R. F. Hughes, "Design Criteria for Mine Clearing Rollers", July 1973, as amended by letter 11/6/73 "Blast Loading of Signature Duplicator."

Structure	Impulse, lb-sec	
	Mine location a	Mine location b
Wheel Face A	--	435
Track Section B	2900	280
Track Section C	4660	620
Track Section D	NIL	365
Total	7560	1700

The total impulse on the structure from a mine directly under the roadwheel is about 3 times greater than the 2,250 lb-sec computed from the 100,000 lb-ft of energy. Since the energy removed from the blast by the fracture of the track would reduce the values given above, the contract energy input guidance was accepted and impulse loadings (above) were scaled to produce a total of 2,250 lb-sec (table XII).

TABLE XII. IMPULSES IMPARTED TO STRUCTURE BY MINE EXPLOSION

Source of impulse	Impulse applied to roadwheels, lb-sec			
	Mine location a		Mine location b	
Wheel Face A*	--		128	Side
Track Section B	803	Up	86	Side
Track Section C	1,447	Up	176	Side
Track Section D	--		103	Side
Total	2,250 lb. sec.		493 lb. sec.	

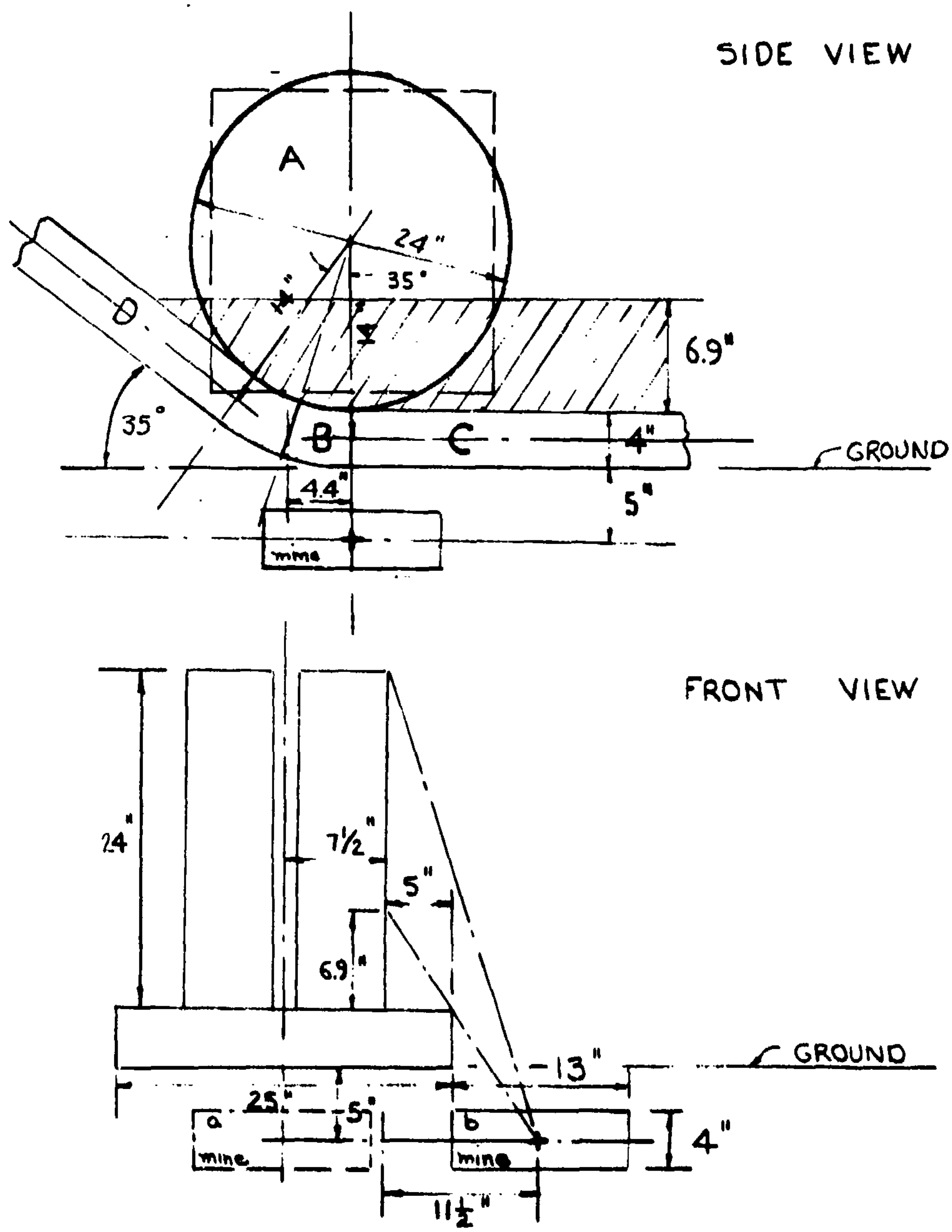


Figure 11. Schematic Showing Mine Location for Blast Effects Analysis

This assumption must be evaluated in relation to test data, since it is critical to the design of blast survivable suspension components. Assuming that blast wave shape shown in figure 10 holds for the two mine locations in figure 11, the impulses shown in table XII can be translated to forces experienced by CTVSD structure at the time of blast as shown in table XIII.

TABLE XIII. MINE BLAST LOADS EXPERIENCED BY CTVSD STRUCTURE

Mine Location a (Vertical blast) Point load on wheel	2.25×10^6 lb.
Mine Location b (Side blast)	
Wheel Face A	126,368 lb.
Track Section B	84,874 lb.
Track Section C	173,521 lb.
Track Section D	101,850 lb.
Total	486,613 lb.

3.4.3 Finite Element Model

The CTVSD hull and suspension structure has been modelled on NASTRAN, a large scale finite element design analysis program. Briefly, finite elements analysis of a continuum involves the following:

- The continuum is separated by imaginary lines into a number of finite elements
- These elements are assumed to be interconnected only at a discrete number of nodal points situated on their boundaries. The displacements of these nodal points are basic unknown parameters.
- A set of functions is chosen to define uniquely the state of displacement within each finite element in terms of its modal displacements.
- The state of strain within an element is now uniquely defined by these displacements.
- A system of forces concentrated at the nodes and equilibrating the boundary stresses is determined.
- Finally, a general assembly of all finite elements is performed to yield the following formulation.

$$[K] \{U\} = \{P\}$$

where

$$[K] = \text{System stiffness matrix}$$
$$\{U\} = \text{Independent degrees of freedom}$$
$$\{P\} = \text{Load vector}$$

The basic problem is to solve this equation for the independent degrees of freedom (eg. deformations) and, subsequently, to extract additional information (eg. stresses, reaction forces, etc.).

A NASTRAN model of CTVSD using plate, beam and spring elements has been made, including:

- 522 finite elements
- 494 nodes
- 2,470 degrees of freedom

The advantage of the finite element model lies in its predictive capability of analysis and ease of evaluation of proposed modifications. Another advantage of the model is the fact that the same model may be used for such varied information as deflection, stress, buckling, vibration, transient, and random response. The primary application of the model will be in future phases, since it has become evident that blast testing is an essential step in development of a definitive model.

3.4.4 Stress Analysis Results

As the study on CTVSD progressed, it became increasingly evident that blast survivability, and not mobility, imposes primary constraints on suspension design. Blast effects from two mine locations have been studied (figure 11):

- Mine centered below track immediately under the front wheel assembly, producing only vertical loads
- Mine offset from the center of the track, producing significant side loads

Several stress analysis iterations have been performed in order to arrive at a balanced design. In order to avoid excessive loading of components from side blast, it was decided to design track centerguides to fail at some predetermined load less than design load of other components and 55,000 lb concen-

trated side load was used as design load. Based on this criterion, factors of safety in major suspension system components are as follows:

TABLE XVIII. SUSPENSION COMPONENT SAFETY FACTORS

Component	Material	Safety Factor
Hub	4340 Steel Hardness Rockwell C 43	1.5
Axle	4340 Steel Hardness Rockwell C 47	1.5
Road Arm	4340 Steel Hardness Rockwell C 40	1.5

3.4.5 Conclusions and Recommendations

- The object of arriving at a balanced design of suspension system has been met.
- Because of uncertainties associated with blast load and simplified assumptions, the analysis must be considered preliminary.
- Adequate instrumentation must be provided in the test rig in order to obtain better definition of loads during blast.
- Adequate design of suspension brackets requires integration with CTVSD hull structure. Since study of CTVSD structure is beyond the scope of the present contract, detailed study of this area has not been undertaken.

3.5 ANALYTICAL STATUS SUMMARY

3.5.1 Status Review

The CTVSD concept analysis effort was concentrated in four general areas. These were vehicle ride dynamics and soft soil performance, mine blast effects on suspension unit dynamics, and a structural and stress analysis of the suspension system members. Standard analytical tools were employed with current existing vehicle computer models modified for unique CTVSD features.

The primary conclusion of the vehicle mobility analyses was that the design latitude afforded by acceptable ranges of suspension system design parameters, as these affect mobility, allowed greater attention to be focused on the response of the suspension system to mine blasts. Each suspension unit can be designed to tend towards minimization of blast damage and still be within the range of parameter variation dictated by the vehicle mobility requirements.

For instance, it would be preferred from a blast damage survivability standpoint to have as heavy a roadwheel as possible. The mobility results indicate that roadwheel weights of up to 1,000 pounds or more do not significantly affect mobility and performance of the CTVSD vehicle when compared to the improved M60 tank.

Soft soil investigations of the CTVSD concept have shown that a considerable number of different blast damaged configurations remain sufficiently mobile to proceed further through the mine field or to withdraw. The most critical blast damaged configurations, those with the damage concentrated in the front quadrants, benefited the most from a rearward shift of center of gravity. The probability of blast damage occurring to the front quadrants is highest due to the fact that the highest incidence of enemy mines is single impulse pressure mines. A full scale effectiveness analysis is required to determine the probabilities of occurrence of mine damage for each damaged configuration.

The analysis of the suspension system response to a mine blast input in terms of energy is an extremely involved process that was beyond the scope of the contract. However, a limited analysis, consisting of conservative estimates of input force and considering rigid body equations of motion, yields indications of suspension system response and an indication of expected problem areas. For instance, standard mobility type shock absorbers do not provide significant energy absorbing capability. However, several promising special devices, such as liquid springs and crushable honeycomb material considered for blast absorption bump stops may enhance blast resistance. The blast analysis also revealed that the roadwheel/roadarm mass ratio should be maximized to reduce forces and moments on the axle and connecting members.

The preliminary structural analysis indicates that a balanced design can be achieved. The preliminary structural and stress analyses also indicate that a total integrated structural and stress analysis of the suspension system attached to the CTVSD hull is required.

The analytical work reported in this section was performed to direct the development of the evolved baseline concept. These tools were then applied again to establish the resultant concept characteristics, which are presented in section 5.0.

3.5.2 Recommendations

Several recommendations have been stated in the appropriate test sections and a reprise is included here.

Ride dynamics studies in the near future should be limited, since the variation of ride parameters allows considerable latitude in the selection of specific values.

Soft soil mobility and performance studies, coupled with mine clearing effectiveness studies, should be performed to determine the critical blast damaged configuration and methods of improvement in design of these configurations to achieve greater mobility performance.

The blast effects model should be improved with the addition of structural elastic and plastic deformation effects and a more specific representation of the mine blast phenomena as they interface with the structure.

Test data should be correlated with structural and stress analysis data to upgrade the structural analyses and to provide more meaningful results and interpretations of analytically derived data. A complete hull/suspension system structural analysis is suggested.

4.0 DESIGN INVESTIGATIONS

4.1 BASELINE DESIGN

4.1.1 Baseline Configuration

The baseline configuration for CTVSD is defined by three elements, each a product of prior joint investigations by MERDC and TACOM:

- TACOM layout LK-10371, dated 6 February 1973, reproduced herein as figure 12
- A weight study and companion layout, dated 1 March 1973, used for reference and not included in this report
- The Contract Purchase Description (CPD) dated 29 January 1973

The baseline configuration provided an excellent point of departure for further design investigations, oriented to the following design objectives:

- Preparation of an "Evolved Baseline Concept", intended to be a complete generation of advancement in refinement and extent of definition
- Layouts and detail drawings of a test rig suspension system

Several problems, questions, or areas of incomplete definition were identified during the initial design stages:

- Need for rear idler to relieve return roller from track tension loads
- Required size of drive sprockets and idlers
- Need for outboard sprocket and idler supports
- Track tensioning systems characteristics
- Shock absorber installation requirements
- Clearance between track guides and front torsilastic springs in jounce position
- L/T ratio (at 1.73) in the area normally considered poor
- Engine power level probably inadequate
- Intent concerning elements to be included in the specified 300 lb roadwheel weight

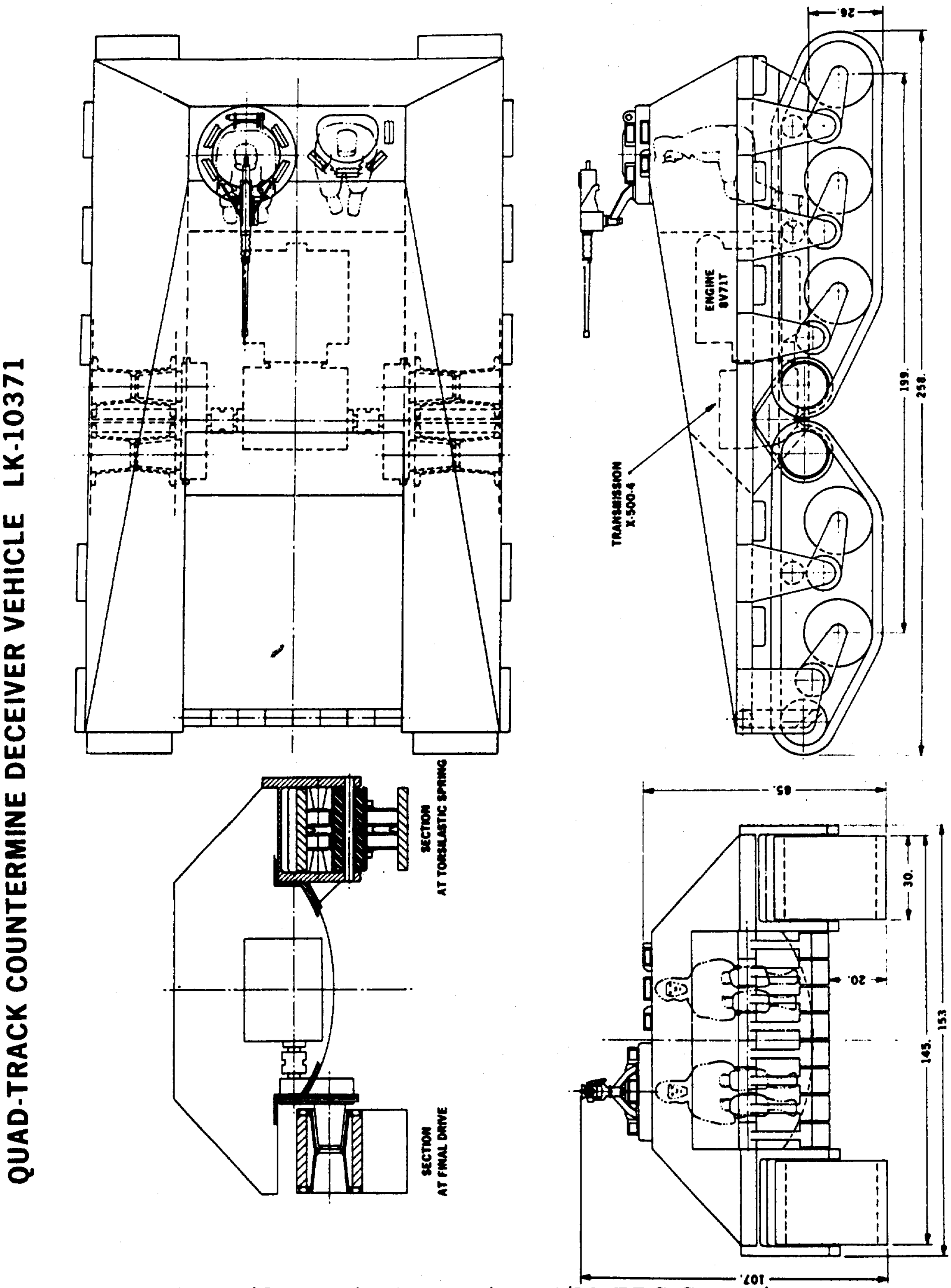


Figure 12. Preliminary TACOM/MERDC Concept

- Need for roadwheel tires
- Return roller size requirements
- Need for a return roller in the front envelope
- Need for holes in roadwheels
- Adequacy of suspension brackets for offset blast loads
- Location of center of gravity
- Bump stop retention when operating against a moving track
- Effects of track breakage on the suspension

These items were discussed intensively by MERDC, TACOM, and Chrysler personnel in the early stage of the contract to arrive at guidelines for further design activities.

4.1.2 Initial Chrysler Concept

Chrysler prepared a sketch layout of a revised concept, which reflected our own tracked vehicle design experience, in particular our background in installation of torsilastic springs. Characteristics of this initial Chrysler concept are compared to the TACOM/MERDC concept in table XIX.

This initial Chrysler concept addressed several of the items listed in paragraph 4.1.1, including:

- Larger sprockets, idlers, and return rollers
- Addition of a rear idler
- Elimination of spring/track guide interference
- Inclusion of track tensioners
- Provision for shock absorbers

The primary effects of these changes were increases in vehicle length and track height, as well as a corresponding increase in sponson height. The length change was not a matter of serious concern, but considerable discussion attended the height increase. The point was made that sponson height is independent of hull height and that the only adverse effect of the sponson height increase was visibility over the front corners. The height was

TABLE XIX CONCEPT COMPARISON		
Characteristic	TACOM/MERDC	Chrysler
Track Height	39.00"	51.50"
Vehicle Length	258.00"	299.50"
Track Contact	199.00"	208.75"
Vehicle Width	153.00"	153.00"
Track Width	30.00"	30.00"
Idler Diameter	16.00"	24.00"
Support Roller Diameter	8.00"	12.00"
Sprocket Diameter	16.00"	24.50"
Roadwheel Diameter	24.00"	24.00"
Forward Arm Angle	28^{o}	38^{o}
Track Approach Angle	25^{o}	28^{o}
Idler at Rear	No	Yes
Track Adjustment/Rear	No	Yes
Track Adjustment/Front	No	Yes
Shock Absorbers	No	Yes

accepted on recognition of the fact that visibility of the track contact area is most significant in the CTVSD mission. Other questions and problems were also adequately resolved in these initial discussions and the initial Chrysler concept was accepted as a sound basis for further design investigations.

4.1.3 Preliminary Design Approach

With the general acceptance of the initial Chrysler concept, attention turned to exploratory study of suspension element installations. This was done on a

series of overlay drawings of individual suspension elements in an iterative process intended to arrive at an optimum suspension arrangement. Design engineering and drafting activities were also interacting extensively with mobility, blast effects, and structural analysis during this period. Design finalization was deliberately resisted until analytical models were operative and capable of influencing the design. Contacts with MERDC and TACOM personnel also continued during this period, and two specific points of guidance emerged during these discussions:

- Reduced track width (24-26") would be preferred
- Reduced vehicle width would improve transportability

These changes would have an adverse effect on L/T ratio, but this was not considered a major constraint with a modern regenerative-steer cross-drive transmission.

Discussion during the preliminary design period also resulted in establishment of several guidelines or conclusions concerning blast effects:

- The track will fail upon mine detonation
- The roadwheel tire will also fail, but in a manner permitting continued mine-clearing operation. Repair action will be required to restore full mobility performance
- The roadwheel rim will distort or fracture, in a manner probably allowing continued operation but requiring repair action for full capability
- Every effort should be made to provide a high probability of blast survival for other elements of the suspension station
- Each suspension must resist a detonation at an adjacent station if the CTVSD concept is to remain viable

Subsequent paragraphs summarize the design process for key subsystem elements.

4.1.4 Shock Absorber

Mobility studies showed that shock absorbers placed at each corner of the vehicle would provide acceptable mobility. The studies also showed that an increase in the number of shock absorbers would provide an improvement in the mobility of the vehicle. This contributed to the decision that the vehicle would be designed in such a manner that shock absorbers could be placed at every wheel position if desired. Another factor in this decision was the

desire to provide for a specialized shock absorber device to aid in dissipation of blast energy. These devices, discussed in paragraph 4.5, would require installation at each suspension station for functional effectiveness. Installation of an automotive shock absorber at each station was provided as a space claim, to facilitate later integration of a specialized shock.

Through many design iterations it was found that a horizontally mounted shock absorber that extends for jounce could provide the best overall damping, since the moment arm length remains nearly constant from free position to full jounce. This system was designed on the assumption that failure of the shock absorber during the after-blast motions of the wheel/arm system was acceptable, since the amount of energy that could be consumed by a conventional shock absorber is low when compared to the total wheel system blast energy. Discussions with automotive shock absorber manufacturers disclosed that:

- The horizontal automotive shock absorber could not be built to accept the overtravel required during blast without special machines and assembly techniques at a much higher cost.

- A shock absorber can withstand twice as much force in compression as it can in tension before it is destroyed.

Since problems were evident in preventing horizontal shock absorber interference with the roadarm in the blast mode, design work was also performed in an attempt to fit a shock absorber into the system that would compress during jounce, would provide the needed overtravel to survive during the blast, and could be produced at a reasonable price. After many iterations we accepted the design discussed in paragraph 4.2.3 because it provided the best tradeoff between mobility, blast resistance, and cost.

4.1.5 Bump Stops

The TACOM/MERDC concept (figure 12) provided large rubber blocks above the track, to serve both as mobility bump stops and for absorption of blast energy. Two possible drawbacks were evident in this system:

- The moving track would be trapped between the stationary block and the wheel. Ability to design a block retention system was questioned

- The evolving Chrysler design concept, with the higher track, increased the travel required to contact the bump stop. This increased travel would cause spring failure

The corollary of the latter item is that additional space is available between the wheel and the track, allowing the bump stop to be installed therein and avoiding the first drawback.

Our initial design consisted of truncated cones of rubber mounted on the suspension support housing to stop the arms during normal mobility and a steel I-Beam mounted above the track to stop the roadwheels during blast. The steel I-Beam was later rejected in favor of a crushable honeycomb material that would not only stop the wheel but would also absorb large amounts of blast energy. The particular material selected is readily available in crush strengths of up to 2,200 psi and can be ordered with crush strengths of up to 5,000 psi. This honeycomb material has a characteristic called compressive peak and experiences a peak load that is about twice the crush strength before crushing action begins. Once crushing begins, the crush strength is nearly constant (see figure 13). To take advantage of this compressive peak we investigated a dual bump stop with a cone of rubber bonded to a block of

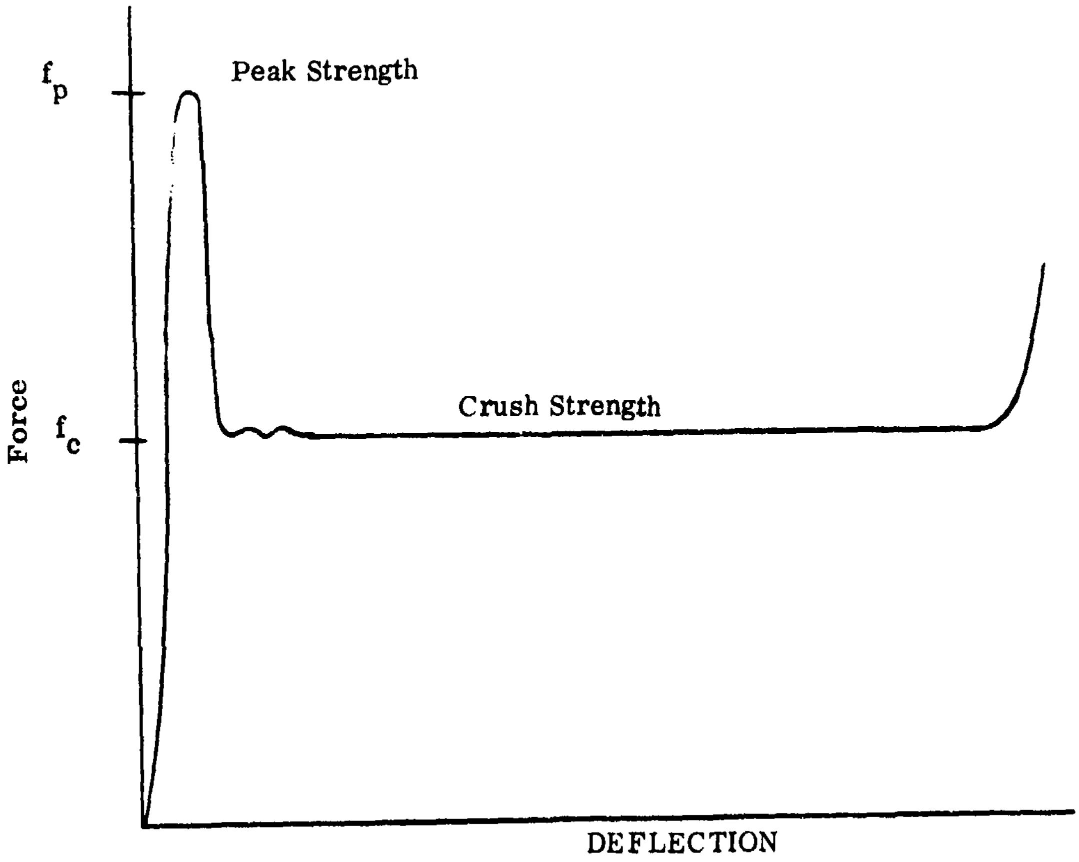


Figure 13 Crushable Bump Stop Characteristics

the crushable material. This bump stop was designed such that the rubber portion would serve as a normal mobility bump stop, with the compressive peak being exceeded only during a blast. After the compressive peak is exceeded, the material will crush from 6 inches to 2 inches and could completely stop the arm in the 4 inches of overtravel. The design appeared feasible, but the results of stress analysis showed excessive forces at the interface of the wheel bearings and the axle. Some other type of bump stop which could stop the arm and roadwheel simultaneously should be provided. This led to the development of a dual bump stop concept in which mobility bump loads were taken on the roadarm and the high inertia loads resulting from blast resisted directly on the wheel.

4.1.6 Track

A track width of 30 inches was a restraint on the CTVSD concept. The track chosen for the preliminary design was the basic T-97 track modified to a 30-inch width. This could be accomplished by one of two methods. The first is a special end connector to make up the 2-inch difference between the T-97 28-inch track and the preliminary design track. The second would require the design of a T-97 type track with increased body and pin length to the required 30-inch width. No detailed preliminary design work was performed on the track, since it was evident that a T-97 track could be modified readily to suit the requirement.

The original 30-inch requirement was predicated on provision of a cleared path for tanks and other tracked vehicles with track width up to 28 inches. This value was later questioned on three counts:

- It would be virtually impossible to steer a 28-inch track inside a 30-inch path
- Two 30-inch paths, established for M60 vehicle width, would not provide for other tanks with different dimensions or for narrower gauge light vehicles
- Work being done in-house at MERDC produced a conclusion that it was not necessary for the track to cover the complete mine to effect detonation

This later work by MERDC resulted in guidance that track width should be 24-26 inches. It was also stipulated that successful operation would sometimes require a double swath, either by using two CTVSD's in formation or by multiple passes of a single unit. Since a new 25-inch track design is available, preliminary investigations were halted at that point.

4.1.7 Hub, Roadwheels, and Arms

Working within the contract design constraints of a 24-inch roadwheel in the 270-300 lb range we designed an integral hub and roadwheel assembly with a total weight of approximately 750 lbs, allowing approximately 150 lbs for the hub, bearings, seals, axle, and attaching hardware.

This design consisted of the integral hub and roadwheel assembly suspended between dual 19-inch arms. As can be seen by figure 14, two different methods of manufacturing the roadwheels were provided by the preliminary design. This design was later judged undesirable for the following reasons:

- An entire hub and roadwheel assembly would require replacement in the event of mine damage
- The large cantilevered sections in the wheel made it susceptible to damage during a blast
- The roadwheel load was not carried straight through the axle bearings.

Further design investigation led to the separate hub assembly with replaceable roadwheels discussed in paragraph 4.2.6.

4.1.8 Springs

The preliminary baseline concept prepared by TACOM and MERDC used a torsilastic spring. The CTVSD spring was designed by CDE with a rate of 350,000 in-lb/radian and physical measurements of 5.90 inch ID, 10-inch OD and 27 inches long, in accord with the recommendations of the Mobility Research Department. This spring rate produced 10 inches of jounce and 6 inches of rebound travel. The rate is within the recommended range and was selected after consultation with the spring manufacturer. These figures were based on a vehicle with 5 roadwheels per side and a GVW of 70,000 lbs. The absence of upper spindle bearings and seals, and the resiliency of the rubber, produces a spring system for high mobility, low maintenance, and blast survivability.

4.1.9 Idlers and Support Rollers

Chrysler chose to use four identical idlers, two in front and two in the rear, permitting the track tension to be adjusted on all four quadrants by means of an M-60 track adjusting link. Our preliminary design used 24-inch idler wheels because the 16-inch idler wheels presented on the baseline layout were too small to accommodate the T-97 type track without causing excessive track pin bushing deflection.

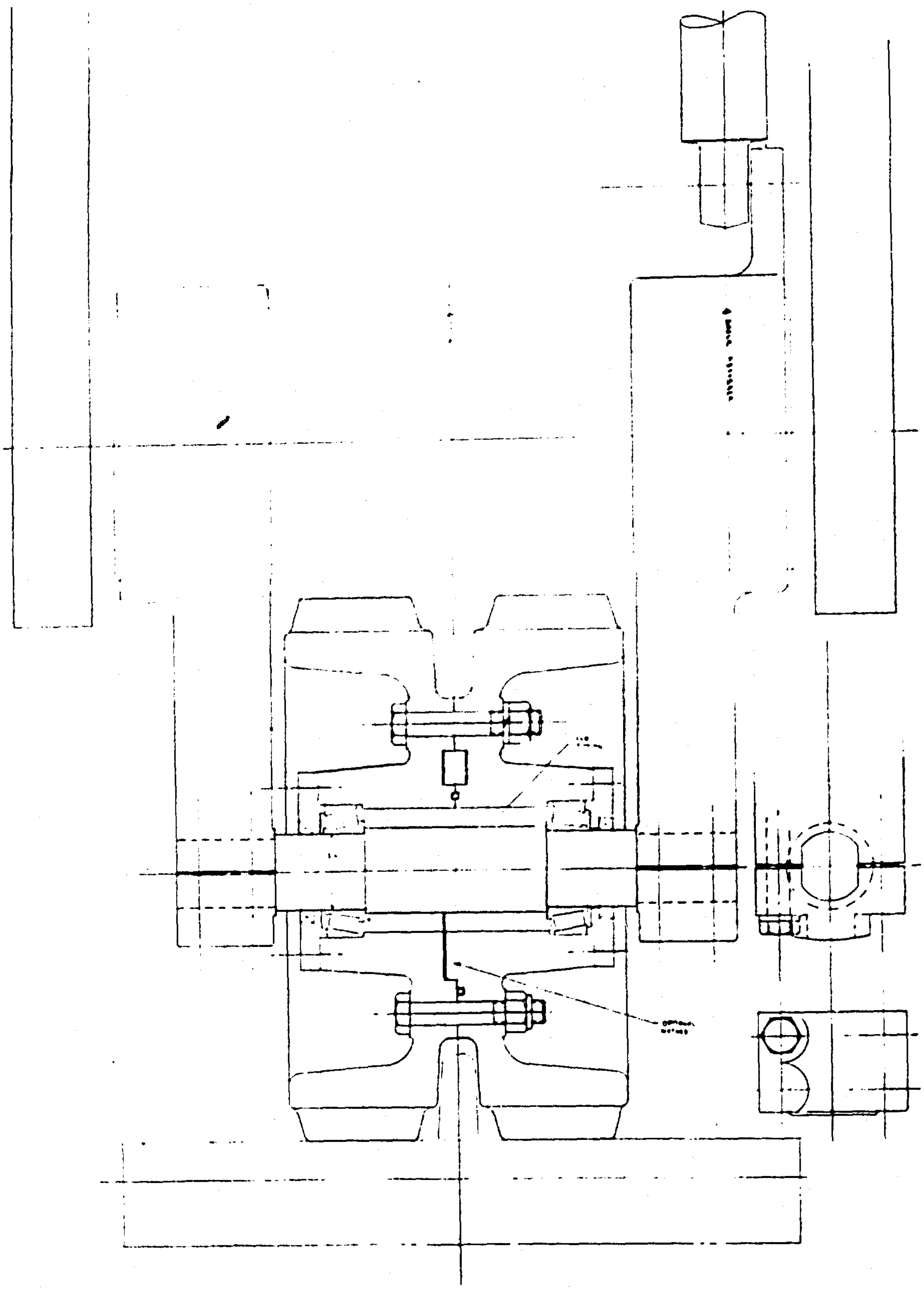


Figure 14 Preliminary Design Roadwheel and Hub

The track support rollers were increased from 8-inch to 12-inch to provide longer life and to permit the use of a larger support roller axle. The preliminary design eliminated the support roller in the front quadrant and only used one support roller in the rear quadrant. However, the evolved baseline concept uses one front and two rear support rollers to allow operation at reduced track tension.

4.2 EVOLVED BASELINE CONCEPT

4.2.1 Evolved Concept Development

The contract requires that an evolved baseline concept design be prepared in accord with the constraints set forth in the purchase description. This was interpreted to mean a generation of advancement over the initial baseline concept (paragraph 4.1.1) in refinement and degree of detail hardware definition. The evolved concept is not necessarily the same as the ultimate CTVSD vehicle design, which will evolve further through subsequent test, investigation, and design activities.

The concept evolved, in part, through the iterative interaction of design and analytical activities described in paragraph 4.1. The other part of the evolution process occurred through interaction of configuration constraints and detail design of test rig suspension elements. The baseline concept drawing presented as figure 15 was actually prepared after all test rig detail drawings were complete. Other drawings in this paragraph used to illustrate the evolved concept design were actually taken from the test rig drawing package.

4.2.2 Configuration

The general arrangement of the evolved CTVSD baseline concept is illustrated in figure 15. Dimensions, weights, and other key characteristics are presented in comparison with the initial TACOM/MERDC concept in table XX. Suspension system elements are described in subparagraphs to follow.

4.2.3 Shock Absorbers

The feasibility of the shock absorber performing a dual function of mobility dampening and blast energy dissipation was investigated during the evolution of the baseline concept. The investigation illustrated that commercially available and typical military shock absorbers could not perform the dual function. Conventional shock absorbers would be destroyed by the blast and require a shear-type mounting bracket to allow total arm travel resulting from mine blast. It was found during the course of the investigation that one manufacturer may be able to design and produce a hydraulic device capable of absorbing the high potential blast energy while still providing proper mobility damping. Investigation of specialized shock absorbers and other special devices, as discussed in paragraph 4.5, is very time consuming and definition could not be concluded within the term of the contract. Further study

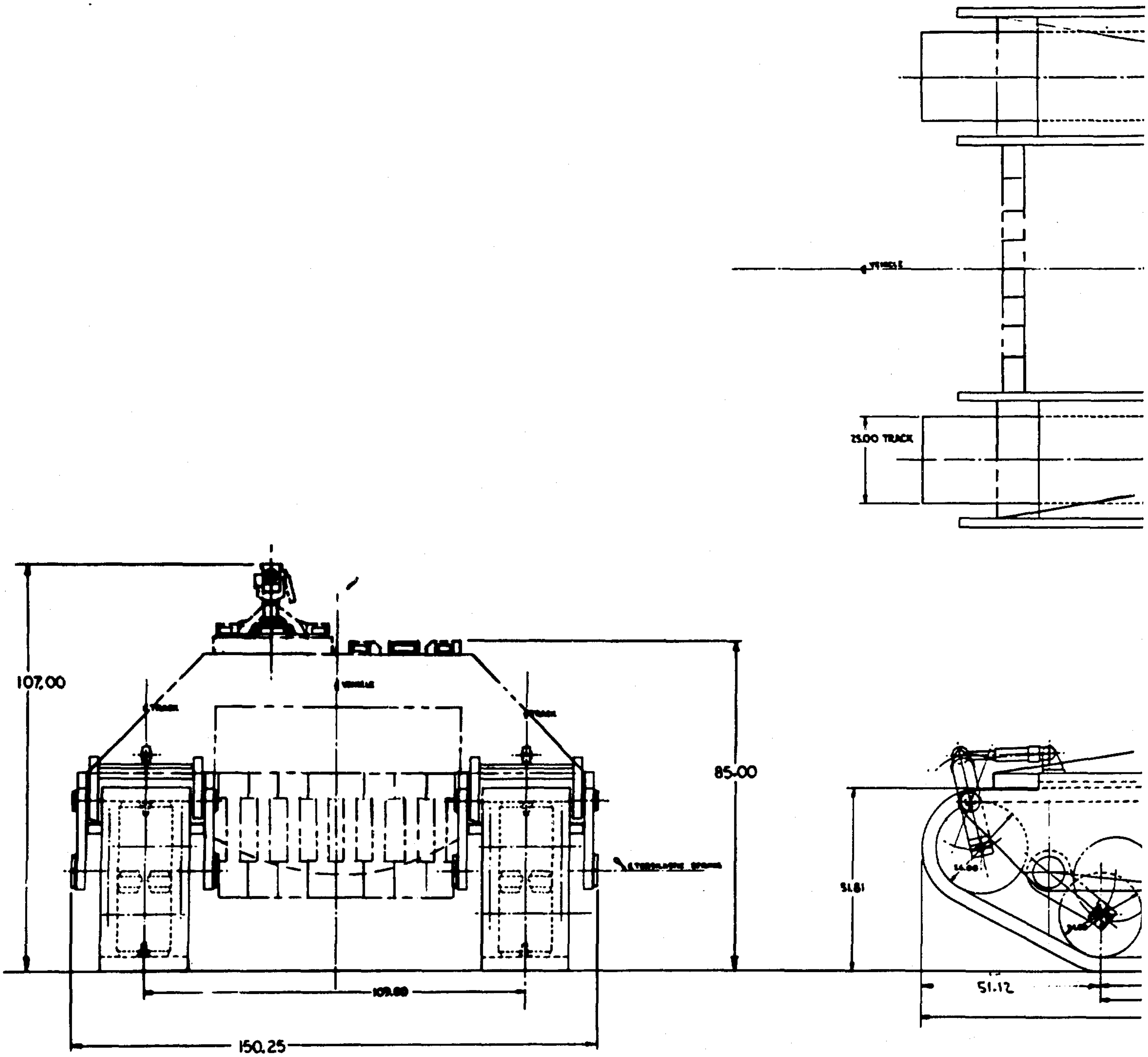


Figure 15 Configuration of the Evolved Baseline Concept

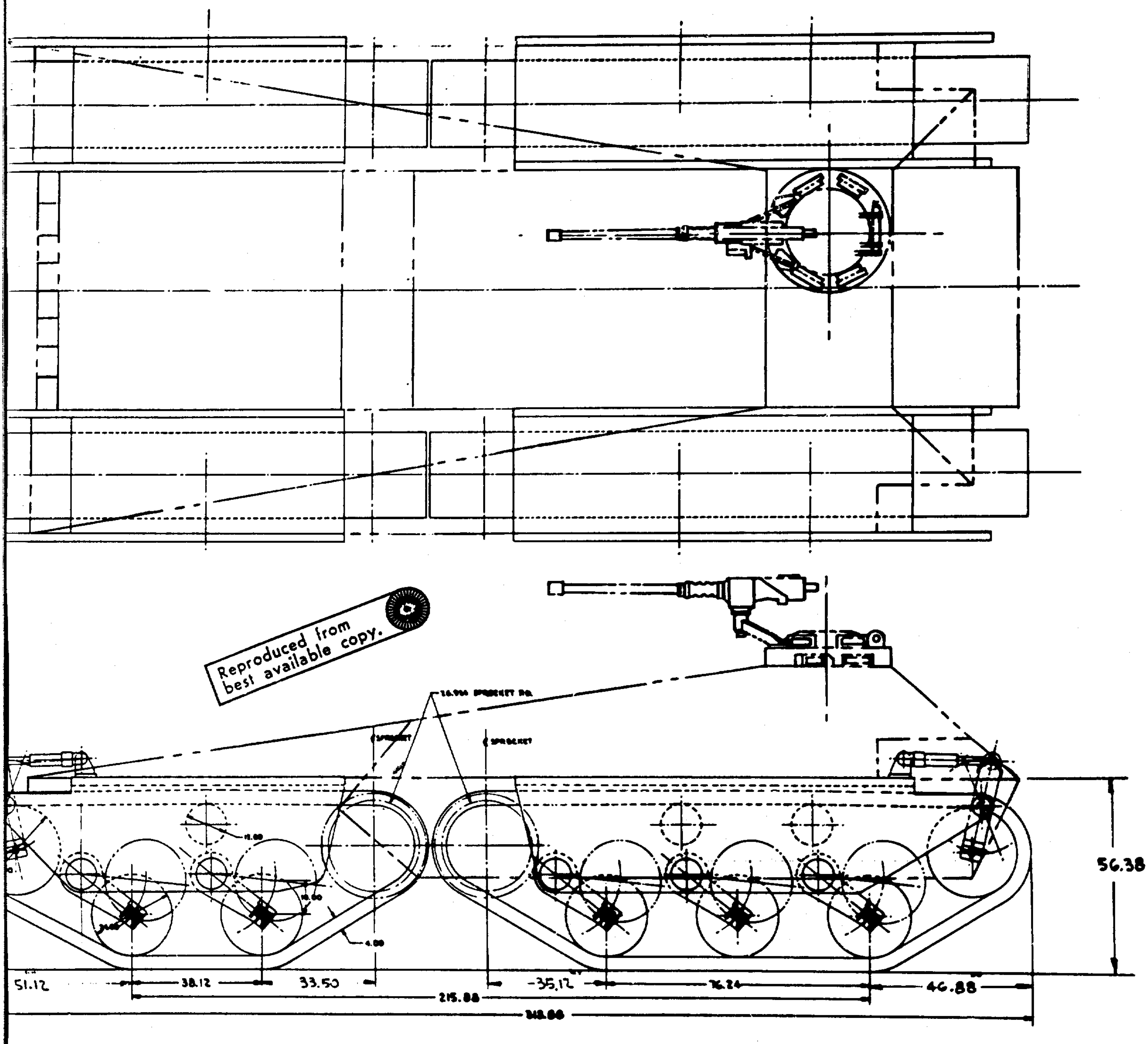

56.38
51.12
38.12
33.50
215.88
-35.12
76.24
46.88

TABLE XX CONCEPT CHARACTERISTICS

CHARACTERISTIC	PRELIMINARY	CURRENT
Idler Diameter - In	16.0	26.0
Support Roller Diameter - In	8.0	12.0
Idler at Rear	NO	YES
Track Adjustment/Rear	NO	YES
Track Adjustment/Front	NO	YES
Track Width - In	30.0	25.0
Shock Absorbers	4 Corners of Vehicle	All Positions
Sprocket Diameter - In	16.0	26.9
Blast Bump Stop	Rubber	Energy Absorbing Crushable Honey-comb Material
Separate Mobility Bump Stop	NO	YES
Vehicle Width - In	153.0	150.25
Ground Contact Length - In	199.0	215.9
Sponson Height - In	44.0	51.8

and design integration will be required at a later date. For this reason, the shock absorber installation shown in figure 16 is for space-claim purposes only. The suspension system may be tested without shocks in the interim if desired.

4.2.4 Bump Stop

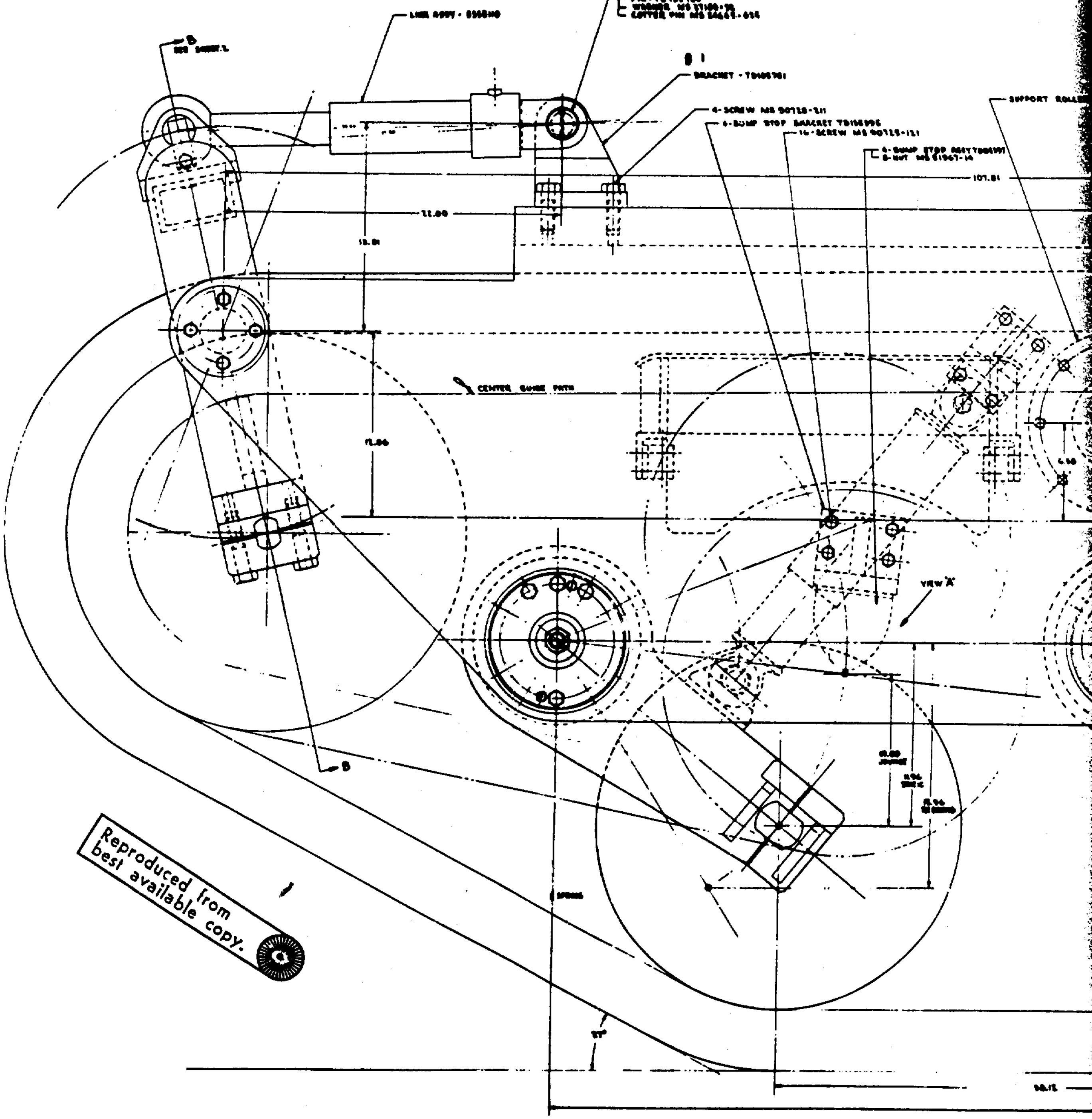
The bump stop on the evolved baseline vehicle (figures 15 and 16) was divided into separate mobility and blast systems to stop the roadarm and the wheel assembly.

The mobility stop is a rubber compression spring on each arm that increases effective spring rate and provides a positive stop for normal vehicle operation. Two mobility bump stops are mounted at each station on a 19-inch moment arm. The load required to collapse these rubber springs rises sharply during the last 1-inch of travel. This rising spring rate, coupled with the torsilastic spring, produces an effective resisting torque at full jounce of over 700,000 in-lb. (See paragraph 4.2.7).

The blast stop has been located under the track and above the roadwheels, above the normal full jounce wheel position. When a blast occurs, the wheel and arm system may have up to 100,000 ft-lbs of kinetic energy, most of which will be stored in the roadwheel mass. When the roadarm fully compresses the rubber mobility stop, the attaching hardware will fail, allowing the wheel to continue upward travel. The mobility bump stop failure removes only a small amount of the stored energy. The wheel then comes in contact with the honeycomb blast stop, described in paragraph 4.1.5. This stop is mounted to supporting members attached to the side plates. These members are designed to shear off and allow the entire assembly to be carried into the track, which then will contact the underside of the suspension support. At this point, the honeycomb material will begin crushing. With a crush strength of 1,000psi and 200 sq inches of material the wheel assembly with 100,000 ft-lb of kinetic energy can be stopped within 6 inches. The wheel will then stop, having traveled 79 degrees from the free position. This over travel is within the stress limitations of the torsilastic spring as described in section 4.2.7.

4.2.5 Track and Sprockets

The track proposed for use on the baseline CTVSD is a 25-inch modification of the T142 type track. This track was selected in accord with the decision to use a 24-inch to 26-inch wide track (paragraph 4.1.6). The track is completely designed at present. The proposed track has undergone limited testing on a Preliminary Suspension Test Rig (PSTR) and performance of the track was found to be satisfactory on both hard surface and cross country terrain.


BRACKET
4-SCREW
4-BUMP STOP BRACKET
CENTER GUIDE PATH
VIEW 'A'

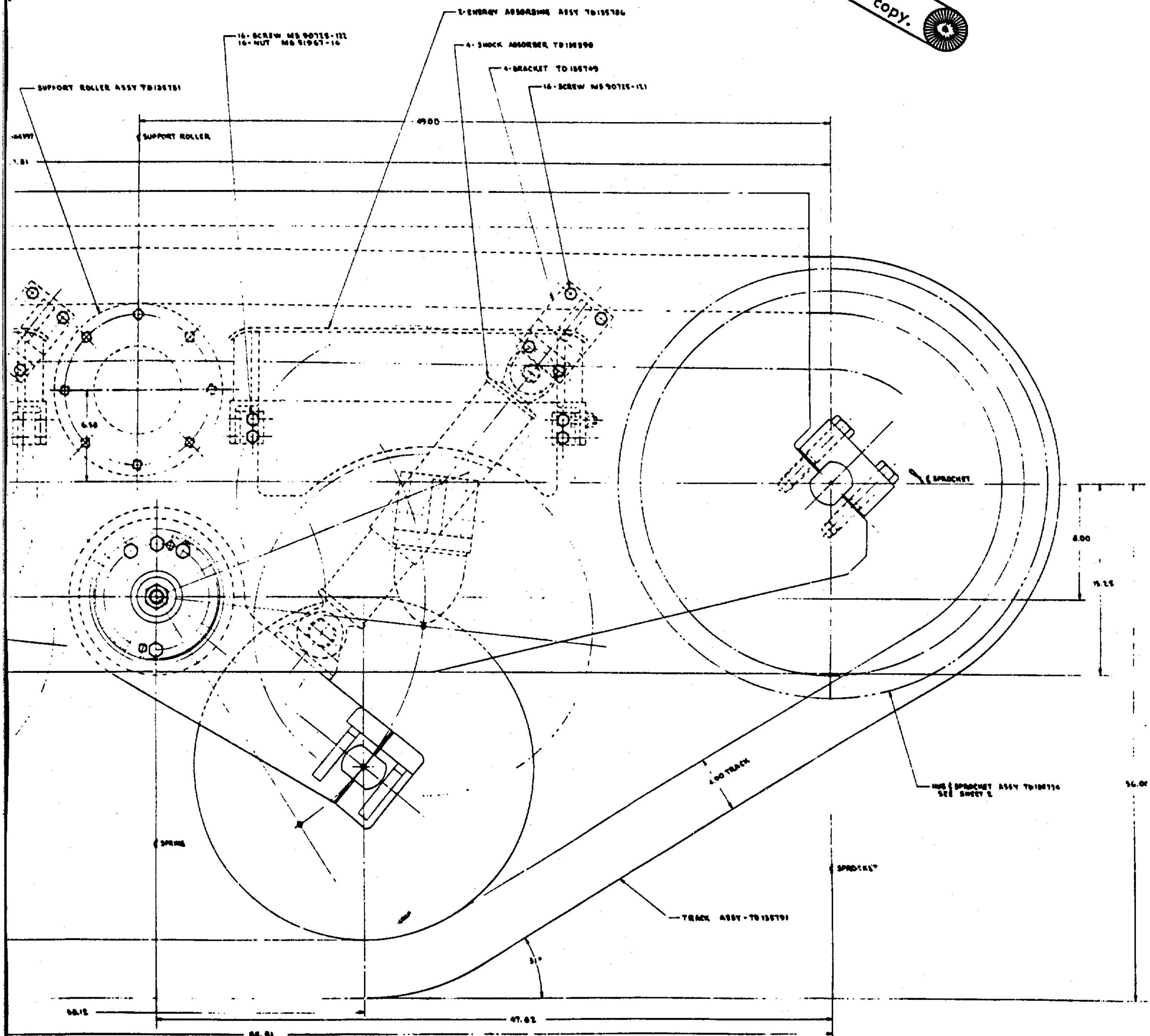


Figure 16 Suspension Installation

The 25-inch modified T142 track is a double pin, rubber bushed track with a pitch of 7.62 inches. Several features of the 25-inch modified T142 track may make it an ideal track for the CTVSD . These features are forged steel binoculars; large, 1-3/8-inch diameter track pins; replaceable road pads and capability of easy replacement of a damaged shoe assembly. This discussion is based on an assumption that a rugged track is appropriate for CTVSD. It may actually be preferable to provide a relatively weak track, which will fail at mine detonation. A failing track would absorb blast energy and would also expose less area to the pressure of the blast, thereby transmitting less impulse to the suspension system. This question can be answered in a future test program.

The sprockets for the concept were previously designed for use with the 25-inch Modified T142 and are completely defined. The interface of the sprocket with the vehicle final drive has not been defined and must be held in abeyance until information on the final drive is available.

4.2.6 Roadwheel, Hub, and Roadarm

As discussed in section 4.1.7, the initial design effort was directed toward providing an integral roadwheel and hub design. Because of its size, weight, and the maintenance problems that resulted from using an integral wheel and hub, the system was optimized by separating the wheels and hub. Figure 17 shows the evolved roadwheel, hub and roadarm arrangement. The roadwheel is 24 inches in diameter, 6.75-inches wide, and has an estimated weight of 298 pounds, which meets the restraints specified in the contract.

Other features of the roadwheel include:

- A wide rim flange on the side for track guidance
- A molded rubber tire
- A symmetrical design to permit mounting in either position

In providing a separate wheel and hub configuration, several advantages were realized. The separate component configuration allows easier assembly of the roadwheel, easier replacement of a damaged roadwheel, and replacement of roadwheels without disassembly of the hub bearings.

The final configuration of the hub resulted in a weight reduction and improved location of the bearings. Radial loads imposed on the hub by the roadwheels pass directly through the centerline of the bearings.

Mobility computer studies show that the ride degrades linearly with increasing roadwheel system mass and that blast energy storage also increases linearly, but at an increased rate, with an increase in the mass. During the extreme

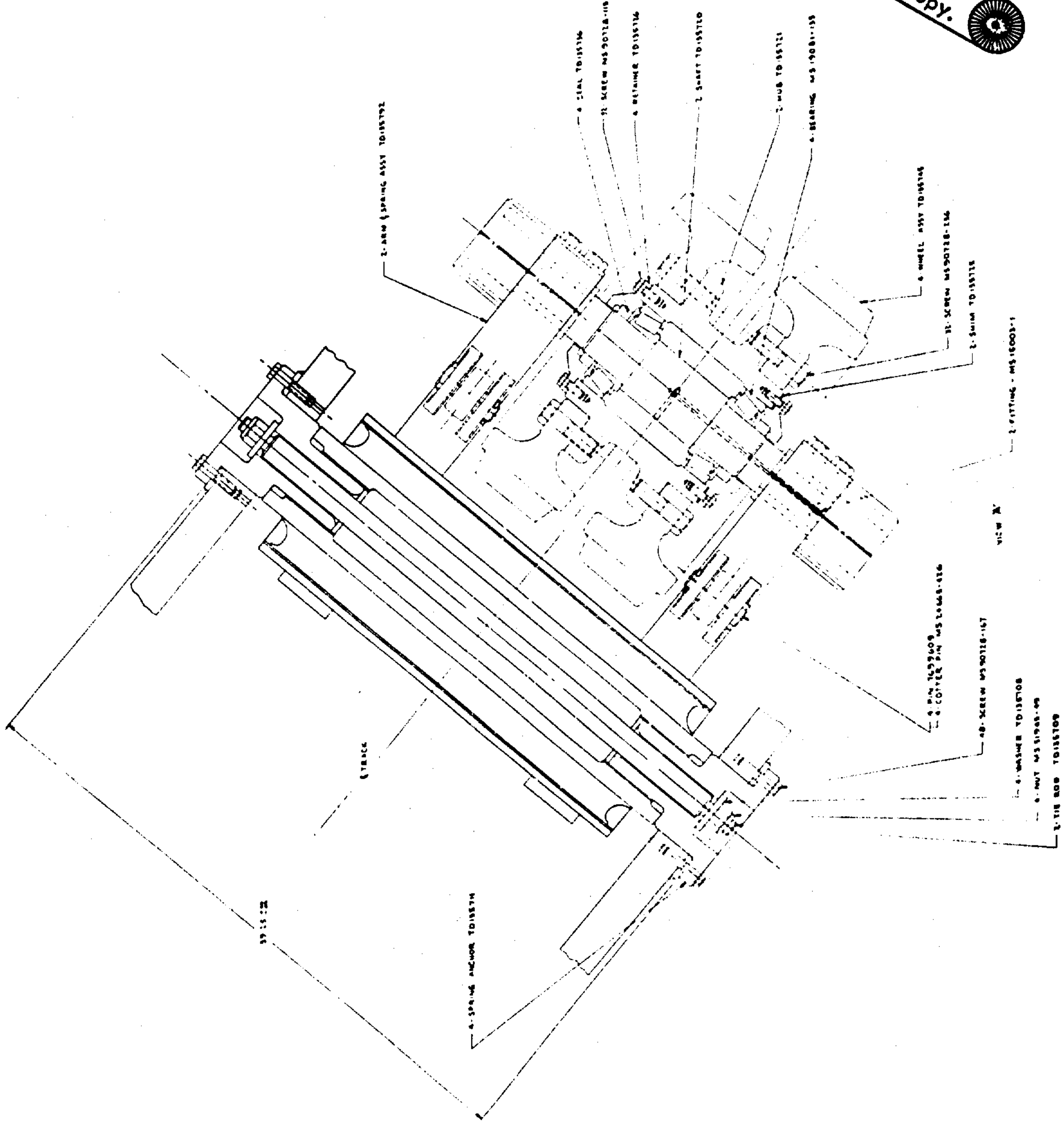


Figure 17 Roadwheel, Hub, and Roadarm Installation

accelerations at the moment of blast, the inertia of the roadarm causes very high wheel bearing loads. Therefore, based on the computer studies, it has been concluded that the roadarm mass should be minimized. The roadarms shown in figure 17 are of welded construction and utilize solid plate for the basic members. This type of construction is the most economical for prototype work where small quantities are to be built, but the roadarm mass is higher than desired. Future studies will determine the feasibility of utilizing tubing or hollow castings for the basic arm members.

The roadwheel and hub system is simple and straightforward, designed primarily to facilitate acquisition of blast test information. The roadwheel tire is expected to fail in the event of mine detonation, but not in a manner that will preclude continued mine-clearing operation. The heavy roadwheel is also expected to fail, but the failure mode is indefinite until testing is accomplished. It is probable that continued operation after a detonation will be feasible, but repair action will be necessary to restore full mobility. Calculations indicate that the hub, bearings, and arm, as well as the spring, will survive the specified blast, but test verification is required.

The roadwheel system is regarded as a promising area for further analytical and test investigations oriented to reduction of blast effects. The objective of such investigations would be to provide for controlled yield or fracture of the roadwheel and/or the attaching hardware.

4.2.7 Springs

The torsilastic rubber spring as described in paragraph 4.1.7 was used in the baseline concept with few changes. The spring rate was changed to 385,000 in-lb/radian to compensate for changes in wheel loading and track tension. The physical size was changed to adjust the spring rate and conform with standard sizes for lower cost. Figure 18 illustrates the rate characteristics of the torsilastic spring and bump stop.

Arm motion while crushing the blast stop requires 28 degrees of overtravel, but this large angle of travel will not cause rubber failure. The stress levels during the normal wheel travel will result in excellent fatigue life. The added torque transmitted to the attaching hardware during the blast overtravel requires a stronger than normal spring-to-arm keying system, as illustrated in figure 17. The spring is mounted to the anchors on splines and the anchors are bolted to the side plates. The entire mount is then clamped together with the 1-3/4-inch tie-rod. With this system, the spring may be indexed on the splines to provide for changing vehicle height if desired.

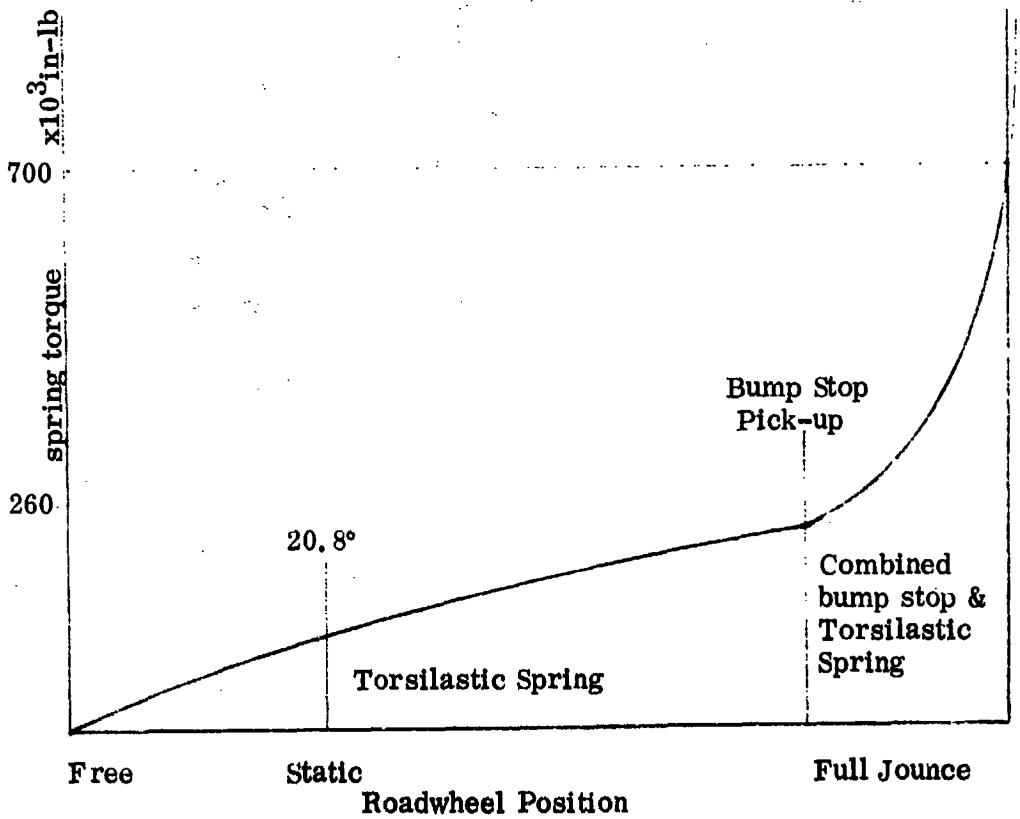


Figure 18. Composite Spring Rate

4.2.8 Track Idlers and Support Rollers

During the preliminary design studies, it was determined that both track idlers and support rollers were necessary for a functional vehicle concept. The small idlers in the initial baseline concept did not provide for initial tensioning of the track and would have resulted in early fatigue failure of the track bushings. The track idlers proposed for the evolved concept have been increased in size and designed to have the capability for initial track tensioning. The concept (figure 19) uses two 26-inch diameter M60A1 roadwheels, suspended between dual pivoted arms, as idler wheels. The idlers are used on all four quadrants of the evolved vehicle. The front two quadrants have the idlers at the front and the rear two quadrants have the idlers in the rear. The pivoted arms can be adjusted through the M60A1 adjusting link, to provide initial track tension. No dynamic compensation is provided, but may be required to insure track tension and retention of track on the vehicle sprocket. Further study of this problem will be required during finalization of a production vehicle concept.

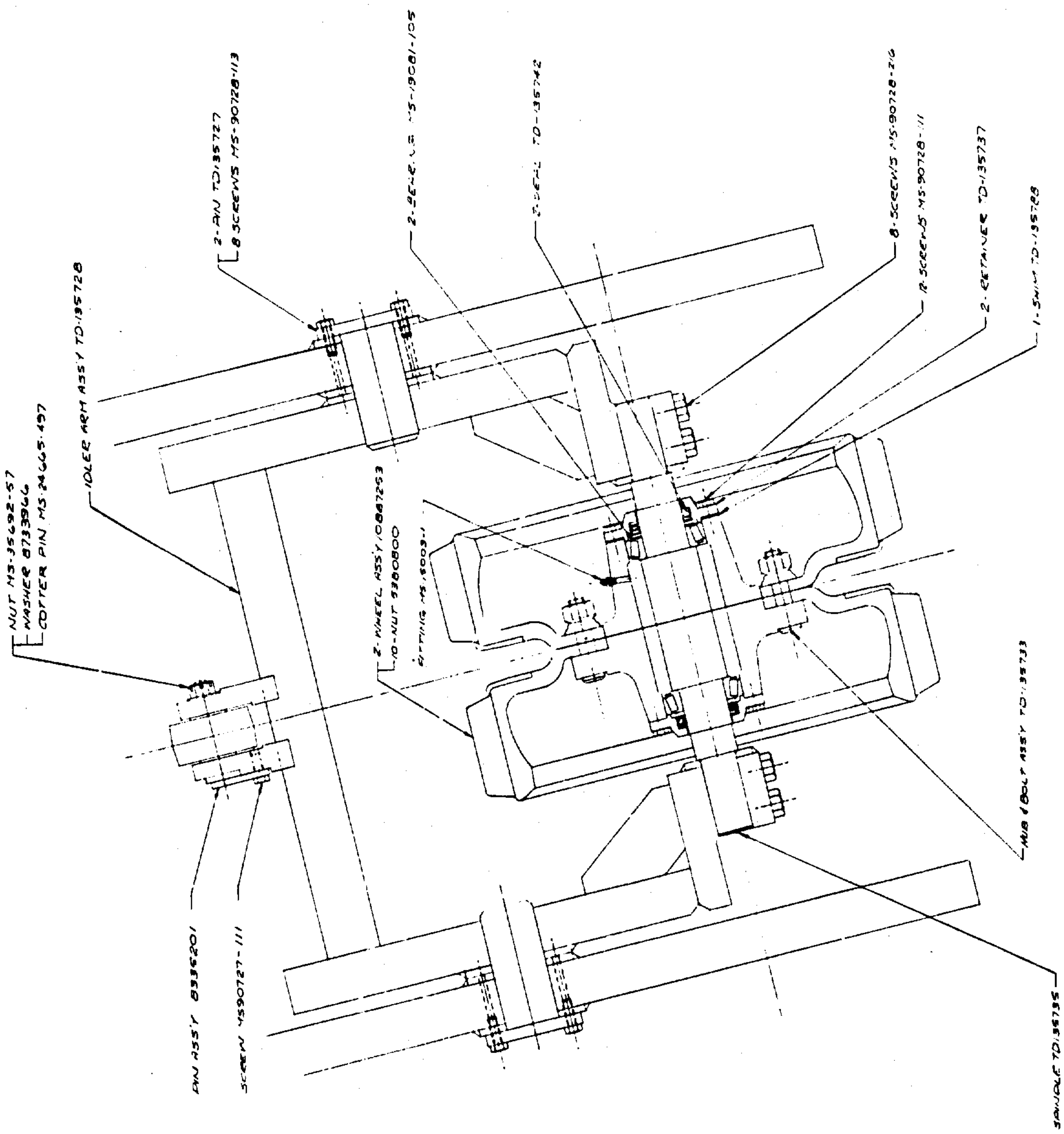


Figure 19. Idler & Mount

In the initial baseline concept, the support roller served as the idler in the rearmost position. In the evolved concept the support rollers serve only as support for the track between the sprockets and the idler. The concept requires one support roller for each of the front quadrants and two support rollers for each of the rear quadrants. The support roller has been designed to use the M60A1 support roller wheel (without the rubber tire) or the M48A3 support roller wheel (without the rubber tire). This provides adequate support for the track, while holding the diameter at 12 inches and minimizing space required for the roller assembly.

4.2.9 Structure

Suspension support structure is indicated in figure 15, with additional detail shown in figures 16, 17, and 19. The structure is adequate for vertical blast, but as discussed in paragraph 3.4, may not be satisfactory for certain offset blast conditions. Resolution of this problem will require integration of the suspension support structure with the hull. No problem is evident in accomplishment of this task, but it is outside the scope of the current contract.

4.3 TEST RIG DESIGN

4.3.1 Arrangement

Figure 20 illustrates the arrangement of the test rig suspension system. The test rig is essentially identical with the front suspension quadrant illustrated in figure 16.

The test rig is designed purely to facilitate acquisition of blast test data and no intention exists to conduct mobility tests. All components are functional in the mobility modes, however, except that the track is undriven. Provision for track drive could be added for later-generation tests, if desired, to facilitate evaluation of the effects of operation with a broken track after mine detonation.

4.3.2 Suspension Components.

Test rig suspension components are as described in paragraph 4.2.

4.3.3 Structure

Design of the test rig structure was not included in the contract scope of work and remains to be accomplished in a later program phase. It is planned to attach the suspension quadrant to an M728 Combat Engineer Vehicle (CEV) for testing. This approach will provide:

- Simulation of a vehicle-like response to blast

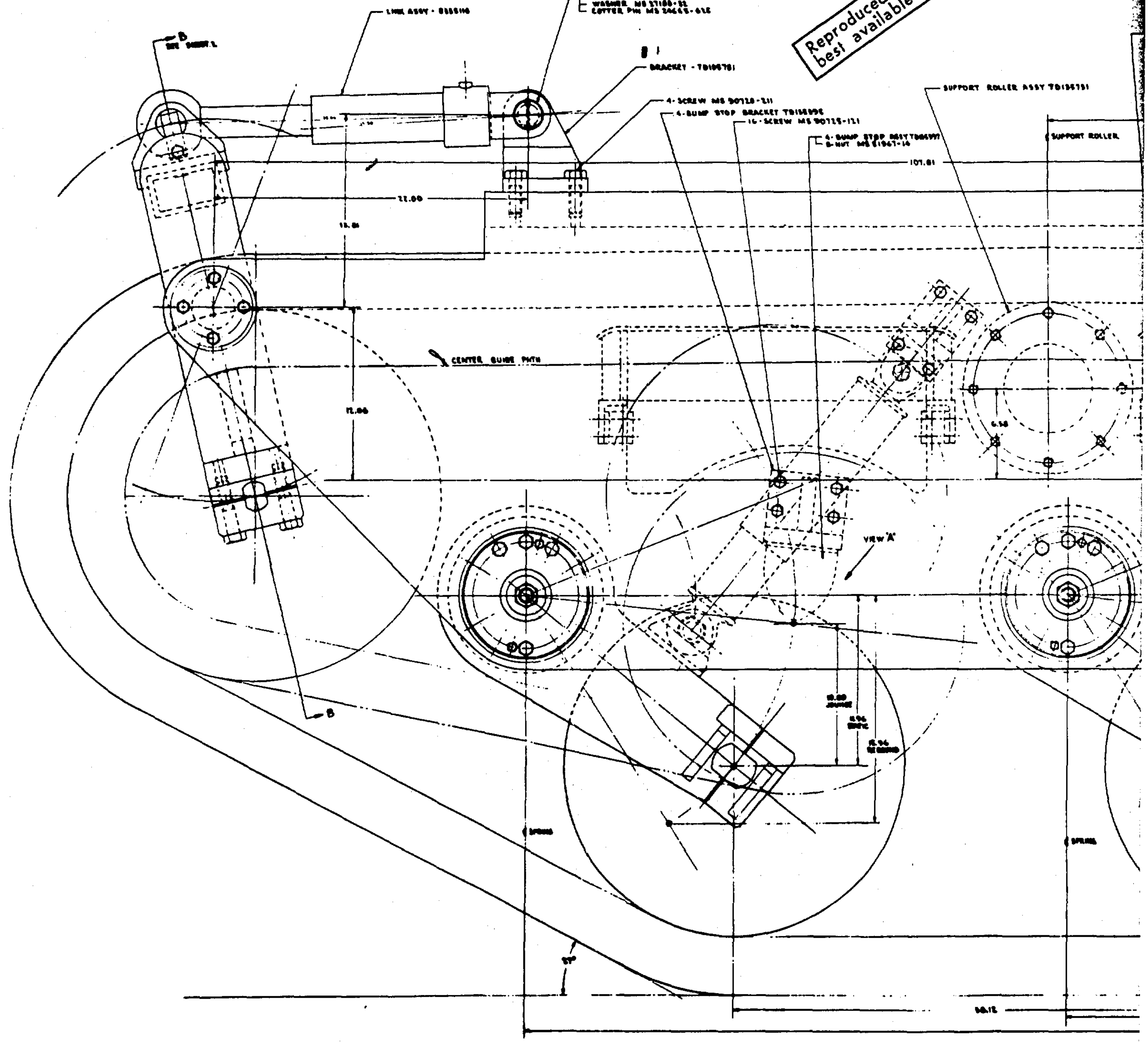
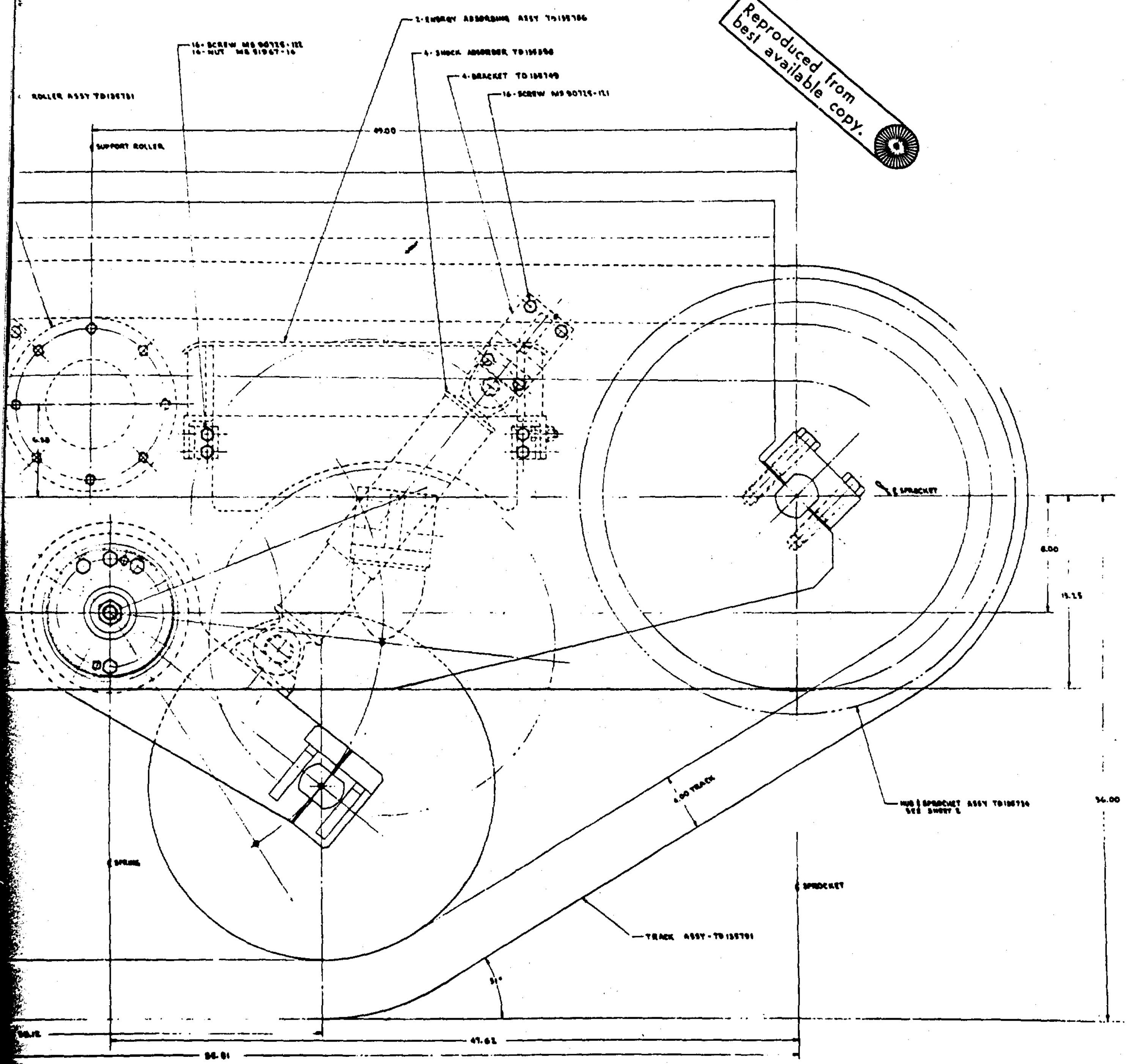


Figure 20. Test Rig Suspension Quadrant


2-ENERGY ABSORBING ASSY
16-SCREW MS 90725-122
16-NUT MS 51967-16
4-SHOCK ABSORBER
4-BRACKET
16-SCREW MS 90725-121
ROLLER ASSY
SUPPORT ROLLER
49.00
6.50
SPROCKET
6.00
15.25
6.00 TRACK
HUB & SPROCKET ASSY
SEE SHEET 2
54.00
SPRING
SPROCKET
TRACK ASSY
51°
47.62
56.81

- A blast resisting mass such that a costly test fixture is not required
- A convenient method of moving the suspension test rig
- A built-in boom for handling test hardware

4.4 SPECIAL DEVICES

4.4.1 Objectives

A critical aspect of the CTVSD suspension system is the response of the system to mine detonation occurring under the track and the resultant transfer of blast energy through the suspension to the hull. It is desirable to minimize this energy transfer to minimize the peak hull acceleration. Another objective is to make each suspension system unit as blast resistant as possible to prevent two adjacent units becoming immobilized with one mine detonation. It is desirable to dissipate energy throughout the system so that no one member of the system is critically overloaded. This is a problem of energy management and special devices exist which exhibit considerable promise in fulfilling energy management roles.

4.4.2 Technologies Investigated

The CTVSD concept is based on application of heavy roadwheels in the blast area, with their inertia used to react against the input inpulse. Assuming that the roadwheel survives the blast, the next problem is to dispose of the stored energy with minimum adverse effect on the vehicle. In addressing this problem, investigations were initiated into technological/industrial areas in which similar problems of energy management exist. These ares included:

- Vehicle suspension systems
- Aircraft landing gear
- Naval aircraft arresting gear
- Spacecraft landing systems
- Crash-resistant automotive bumper systems
- Press die springs
- Transportation packaging systems

A wide array of devices was identified for potential application to the CTVSD problem. Special devices that have been investigated to enhance the blast resistance characteristics of the CTVSD have been grouped into four general categories:

- Hydraulic devices
- Crushable devices

- Resilient devices
- Frangible devices

Investigations of these special devices through contact with suppliers has resulted in several promising alternate designs for blast energy management.

4.4.3 Discussion

Hydraulic Devices. Hydraulic devices have been considered for application in the CTVSD as the replacement for the standard mobility type shock absorber. These devices include liquid springs, modified crane buffers, and shock absorbers with special orifice designs.

The liquid spring concept derives from a recently refined technological discipline. The devices use a special compressible fluid to achieve the spring function and special metering orifices to control flow past a piston head from one chamber to another. The design of the orifices and their fluid metering characteristics can be tailored to accommodate a wide variety of design constraints and dynamic conditions. The design can provide for use as standard mobility type shock absorbers operating in a low load, low velocity, high cycle life environment and as blast energy absorbers in a high load, high velocity, short cycle life environment. Preliminary investigations of these indicate that a device occupying acceptable space and operating as a standard mobility type shock absorber may have the additional potential for absorbing up to the full 100,000 ft-lbs of energy input to the suspension unit system. Smaller units, acting in consonance with other energy absorbing devices, would absorb less energy and leave the remainder to other devices. Future design effort should determine the specific energy management levels in a multidevice system. These energy absorbing hydraulic devices are state-of-the-art and require very little redesign for the stringent CTVSD blast conditions.

Crushable Devices. Crushable devices considered for application to the CTVSD suspension unit pertain primarily to the roadarm and roadwheel bump stops and to energy absorption at these points. The vehicle has a suspension unit mobility bump stop that interacts with the roadarm at 7 inches of jounce. Subsequent to a mine detonation, the roadwheel travels upward, contacts and displaces the mobility bump stop and contacts the crushable roadwheel bump stop. Crushing is an energy absorbing technique that provides another approach to energy management. Investigation of these crushable materials indicates that a wide variation in energy absorbing characteristics can be obtained.

Resilient Devices. Resilient devices considered for use in the CTVSD concept consist of large rubber (or similar material) roadarm bump stops measuring up to 8 inches in diameter and 7 inches thick. This bump stop would come in contact with the roadarm at 7 inches of jounce. It would be designed such that it would act as a mobility bump stop for the first 2 to 3 inches of collapsed

distance with relatively low crush forces and as an energy storer for the last 4 to 5 inches with a very high crush force. The energy is stored and is released as the roadwheel moves downward off the bump stops. As such, the energy is transferred into wheel motion. This device is not an energy absorber and dissipator, but rather an energy storer.

Frangible Devices. Frangible devices fracture in a prescribed manner. The act of fracturing is a valid method of absorbing energy before such energy is transmitted to other structural members in the system. An example of a frangible device is the typical hand grenade with the case of the grenade scored so that after detonation shrapnel of a prescribed size, shape, and weight are obtained. The roadwheel can be designed similarly to fracture in a prescribed manner to assist in energy absorption.

4.4.4 Conclusions

Several conclusions are evident from preliminary investigations:

1) Special devices as described above are candidates for the CTVSD.

2) Hydraulic devices such as liquid springs can fit into an acceptable space envelope.

3) Crushable devices such as honeycomb material can be designed to accept nearly all of the energy input from mine detonation.

4.4.5 Recommendations

1) Further design effort on the CTVSD concept should:

   - Consider special energy absorbing devices for the shock absorbers and roadarm and roadwheel bump stops.

   - Investigate other methods of energy absorption that may be more applicable in terms of size, weight, and cost per unit of energy absorbed.

2) Blast tests should be conducted with special energy absorbing devices installed in the suspension test rig to validate analytical results and to enable the selection of the particular combination of special devices to insure suspension system energy management.

4.5 DESIGN STATUS SUMMARY

4.5.1 Status Review

Through a series of discussions with MERDC and TACOM personnel, along with an iterative series of design and analytical investigations, an evolved

baseline concept design has been developed. The design differs in many significant details from the initial TACOM/MERDC baseline concept, but the functional effectiveness of the system has not been compromised. The most significant changes are:

- Larger idlers, sprockets, and return rollers
- Provision of dual shock absorbers at all stations
- Revised forward arm angle
- Provision for track adjustment
- Change from 30-inch to 25-inch track width
- Addition of a rear idler

Important notes concerning design characteristics are listed below:

- Each suspension station is straddle-mounted on dual roadarms
- Shocks are mounted on top of the roadarms
- The shocks will fail under blast loading
- The mobility bump stop operates against the roadarm
- The blast bump stop operates against the roadwheel. It is positioned below the track and absorbs energy with a crushable material
- The track is a ruggedized 25-inch version of the T-142
- The roadwheel and hub system is a three-piece assembly
- Springs remain torsilastic

A complete test rig assembly drawing and a set of detail drawings has been completed and procurement may be initiated immediately, if desired. Two items of additional design work should be considered prior to test:

- Further investigation of special devices
- Integration of suspension and hull structures

Further design work is also required on a test fixture.

The current view of the concept characteristics is encouraging and Chrysler considers the concept to be feasible. Further discussion of concept characteristics is presented in section 5.0.

4.5.2 Design Recommendations

Recommendations are as follows:

- Continue investigation and design integration studies on special devices.
- Conduct further design studies on structure.
- Design a test fixture.

5.0 SYSTEM CHARACTERISTICS

The process of defining a vehicle concept is essentially iterative, and several "point designs" have been established during definition of the current CTVSD concept. At each point in this process, we have initiated or redirected analytical and design studies to move to a more nearly optimum next-generation system. Tracking of this complex process in a final report is not feasible, but an effort has been made to describe the highlights. Section 3.0 has described the analytical work that contributed to the design process and Section 4.0 presented the key elements of the design evolution.

The objective of this section is to present a complete description of the capabilities and characteristics of the current concept, which has involved a reapplication of all of the analytical techniques applied during concept development. It should again be noted that the current "Evolved Baseline Concept" is one point design in the process of final concept definition, which will be accomplished only after further test, design, and analytical work in future program phases.

5.1 PHYSICAL CHARACTERISTICS

The general arrangement of the CTVSD evolved baseline concept is shown in paragraph 4.2, figure 15. Table XX, comparing key characteristics of the evolved baseline concept and the initial TACOM/MERDC concept, has been expanded in table XXI to give both physical and functional characteristics of the Evolved Baseline Concept incorporating the CDE suspension system and the TACOM/MERDC hull system. The data in table XXI, together with added details of spring and shock absorber dynamic characteristics, were used as inputs to a performance analysis of the evolved baseline concept.

5.2 MOBILITY

This mobility performance update is divided into sections on ride performance and soft soil performance of the CTVSD evolved baseline concept. Comparisons have been made with earlier estimates of vehicle parameters affecting mobility performance.

5.2.1 Ride Performance

An assessment of the ride dynamics performance of the current CTVSD concept is presented in this paragraph. Section 3.1 covers the ride investigations to the point that recommendations were made to design engineering. These preliminary studies indicated that reasonable component weight increases could be tolerated, from a vehicle ride standpoint, if necessary to improve blast survivability. Paragraphs to follow summarize the effects on ride dynamics of a vehicle system designed to survive specified blast loads.

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TABLE XXI. CTVSD EVOLVED BASELINE CONCEPT, PHYSICAL CHARACTERISTICS

Overall Dimensions, Inches	
Length	313.88
Width	150.25
Height	
To sponson	51.81
To top of cupola	85.00
To top of machine gun	107.00
Width of track	25.00
Length of ground contact	
Front	38.12
Rear	76.24
Tread	109.00
Center of gravity, from front of vehicle	164.1
Total ground contact area, square inches	5,918
L/T Ratio	1.98
Weights (including magnetic signature blocks), Pounds	
Gross vehicle weight	95,859
Hull to sponsons	33,845
Sponsons to ground	62,014
Sprung Weight	80,577
Unsprung Weight	15,282
Wheel assembly (2 wheels and hardware)	814
Roadarm assembly (2 arms and hardware)	563
Suspension spring assembly	323
Ground loading at each wheel	9,586
Suspension spring rate, lbs per inch of wheel travel (1)	1,058
Jounce travel, inches	10.0
Natural frequencies of motion, Hertz	
Bounce	1.13
Pitch	1.42
Nominal unit ground pressure, PSI	16.2
VCI (2)	
For one pass	42
For 50 passes	104

Specific Power, Engine Flywheel Horsepower Per Ton	
450 HP engine (used in analysis)	9.4
600 HP engine	12.5
Shock Absorbers (tentative)	
Type	Linear, similar to M60
Locations	2 per wheel station
Blow-off force (at 1.7 inches per second), pounds	2,500
Damping force, (at 10 inches per second), pounds	
Jounce	3,250
Rebound	4,300
Stroke, inches	8.56
Mobility Bump Stops	
Type	Rubber
Locations	One for each roadarm
Total travel, inches	3
Force at full deflection, pounds	40,000
Blast Bump Stops	
Type	Covered aluminum honeycomb
Locations	Over each roadwheel
Initial crush force, per wheel station, pounds	463,200
Sustained crush force, per wheel station, pounds	231,600
Total crush travel, inches	5.3
Energy absorption per wheel station, lb-ft	102,000
Pitch Moment of Inertia of Sprung Mass about vehicle CG, inch-pound-second^2	896,013

(1) With the roadarm horizontal.

(2) Approximate soil strength (in terms of rating cone index averaged over the 6 to 12 inch depth) required to permit the specified number of passes of the undamaged CTVSD.

5.2.1.1 Ride Dynamics of Current CTVSD

The major changes from the preliminary to the current CTVSD are increased sprung and unsprung weights, increased suspension component weights, increased spring rate, and greater damping. Final adjustments of all inputs were made with latest estimates of component characteristics, weights, and locations. Comparisons of key ride dynamics inputs are shown in table XXII.

TABLE XXII. COMPARISON OF KEY INPUTS TO RIDE DYNAMICS ANALYSIS

PARAMETER	PRELIMINARY DESIGN	CURRENT CTVSD
Gross vehicle weight, pounds	70,000	95,859
Sprung weight, pounds	60,000	80,577
Unsprung weight, pounds	10,000	15,282
Roadwheel weight (includes 1/2 of roadarm weight), pounds	800	1,096
CG location, inches from front	157.0	164.1
Pitch Moment of Inertia of sprung mass about vehicle CG, in-lb-sec^2	1,000,000	896,613
Individual spring rate, in-lb/rad	300,000	381,338
Damping curve:		
rate - lb-sec/in	350	1,340
blowoff in jounce, lb	3,500	2,560
Shock absorber positions	all	all
Mobility bump stop, pounds: inches	20,000:3	40,000:3
Jounce travel, inches	10	10

The effects of larger sprung mass, increased suspension spring stiffness and reduced moment of inertia are reflected in a comparison of pitch and bounce natural frequencies. Bounce natural frequency decreased from 1.16 to 1.13 Hz and pitch natural frequency increased from 1.14 to 1.42 Hz. The pitch frequency is higher than that of a tank of similar sprung weight because the mass of the CTVSD is closer to the center of gravity. The possibility of resonance at the pitch natural frequency, however, will be minimized by the high degree of suspension damping. A comparison of spring and damping curves is presented in figures 21 and 22. The higher damping at low velocity of of the final shocks is largely responsible for retention of ride quality of the heavier final configuration.

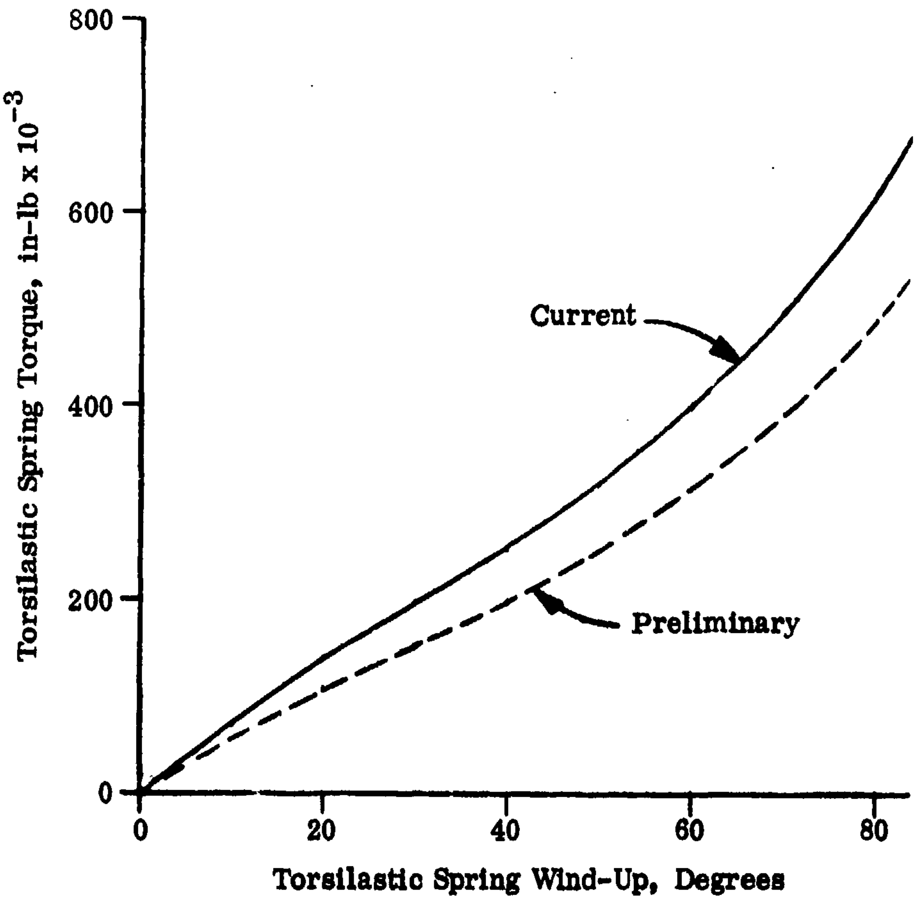


Figure 21. Torsilastic Suspension Spring Functional Characteristics

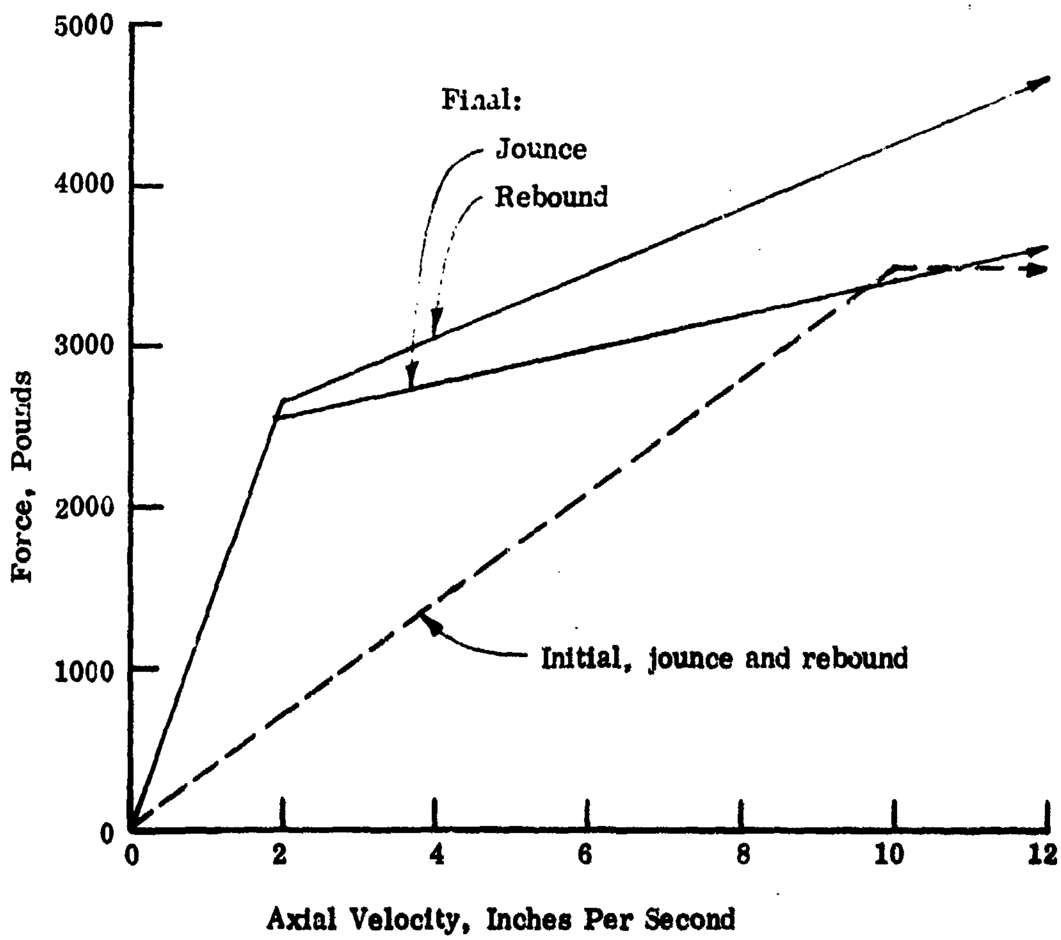


Figure 22 Comparison of Shock Absorber Functions

The net effect of all revisions has been slight reductions in the ride-limited speeds on most of the six terrains. However, these reduced V-ride speeds compare favorably with the M60A1(PI) and are higher than M60A1 speeds as shown in table XXIII.

TABLE XXIII. COMPARISON OF RIDE-LIMITED SPEEDS, MPH

TERRAIN	CTVSD PRELIM	CTVSD CURRENT	M60A1	M60A1PI
Random 3" RMS	25-30	21	14	21
Random 5" RMS	9	6	6	8
Rocky (Ft. Knox)	14	6	2.5	12
Mild (Ft. Knox)	30-35	25	20	21
Medium (Ft. Knox)	25-30	25-30	14.5	16
Perryman (APG)	9	9	4.5	6.5

This summary analysis has substantiated the prior contention that the suspension can tolerate substantial variations in the design to improve blast survivability. The factors that favor the CTVSD suspension over the M60 suspensions are longer wheelbase (216 vs. 167 in), greater jounce travel, and increased damping (20 shock absorbers versus 6). Thus, if the final CTVSD is provided with adequate horsepower to achieve ride-limited speeds, it will be compatible with tank operations.

5.2.1.2 Conclusions

The final version of the undamaged CTVSD will be able to pace a column of M60A1 tanks if adequate horsepower is provided.

5.2.1.3 Recommendations

In the further evolution of CTVSD design, consideration should be given to ride dynamics in design/performance trade studies.

5.2.2 Soft Soil Performance

The two major changes to the CTVSD that affect soft soil mobility are the increase in gross vehicle weight from 70,000 pounds to 95,859 pounds, and a 27.6-inch rearward shift in the center of gravity. This shift was made to equalize wheel loads.

5.2.2.1 Comparisons for Undamaged Configurations

In the undamaged configuration, the current CTVSD with 450 hp achieves 21.3 mph under baseline conditions ($RCI_9 = 158$, 0% slope) compared with 29 mph for the M60A1 (figure 23). Assuming speed increase proportional to engine horsepower increase, a CTVSD with 600 hp would have equal speed capability on the level and slightly greater speeds on the slope compared to the M60A1. Figure 24 presents the same data for the preliminary version for comparison purposes. Although the current CTVSD shows less speed potential, both will require more horsepower to equal M60A1 performance.

5.2.2.2 Blast-Damaged Configurations

Table XXIV presents comparative data on the effects of blast damage on speeds of the preliminary and current CTVSD's in three soils and on two terrain slopes. There are at least two significant trends in these data. First, the equalization of wheel loads definitely increases the number of "go" configurations having front quadrant damage, even with higher vehicle weight. This is accomplished at the expense of reduced mobility of configurations having damage to rear quadrants, the less probable condition.

Secondly, it is apparent that mobility is maintained, especially in the more important stronger soils, for extensively damaged configurations. The configurations given in table XXIV cover all those having at least one intact quadrant per side after having sustained up to five mine blasts. Lacking definitive information on the types and aerial density of mines to be encountered, it was not possible to conduct a meaningful mission effectiveness assessment. It can be said of this analysis, however, that the probabilities of retaining mobility after repeated blast exposures appear favorable.

5.2.2.3 Soft-Soil Mobility Improvement

The number of "no-go" configurations in table XXIV (speed = 0) is related directly to the motion resistance of unpowered roadwheels after a mine blast has removed the track. The motion resistance of an unpowered wheel varies approximately with the inverse cube of ground pressure, such that a small change in ground pressure has a profound effect on motion resistance. A desired decrease in ground pressure can be achieved by reducing the load carried by the wheel or by increasing ground contact area. Three major factors mitigate against larger wheel diameters: increased track envelope size, increased suspension weight and increased wheel area exposed to blast (greater blast energy imparted to the wheel). Wider wheels should be considered, however. When a blast is sustained by an intact suspension quadrant, the blast energy imparted to the quadrant is related to the area of the track exposed to the pressure wave. Each wheel station has been designed to absorb energy remaining after track fracture. Energy-absorbing devices are "spent" during this process (see paragraph 5.3). Thus, it is probable that a subse-

At RCI_9 = 158 & 0% Slope		Left		Right	
		Front	Back	Front	Back
Quad Loading, lbs.		19,225	28,706	19,224	28,705
Sinkage, inches		1.3	0.9	1.3	0.9
Mean Ground Pressure, psi		20.2	15.1	20.2	15.1
Gross Traction, lbs.		23,427		23,426	
Drag, lbs.		794		794	
% Slip At	0% Slope	1.3		1.3	
	5% Slope	4.3		4.3	
	10% Slope	7.3		7.3	
Steering Effort, %		0			

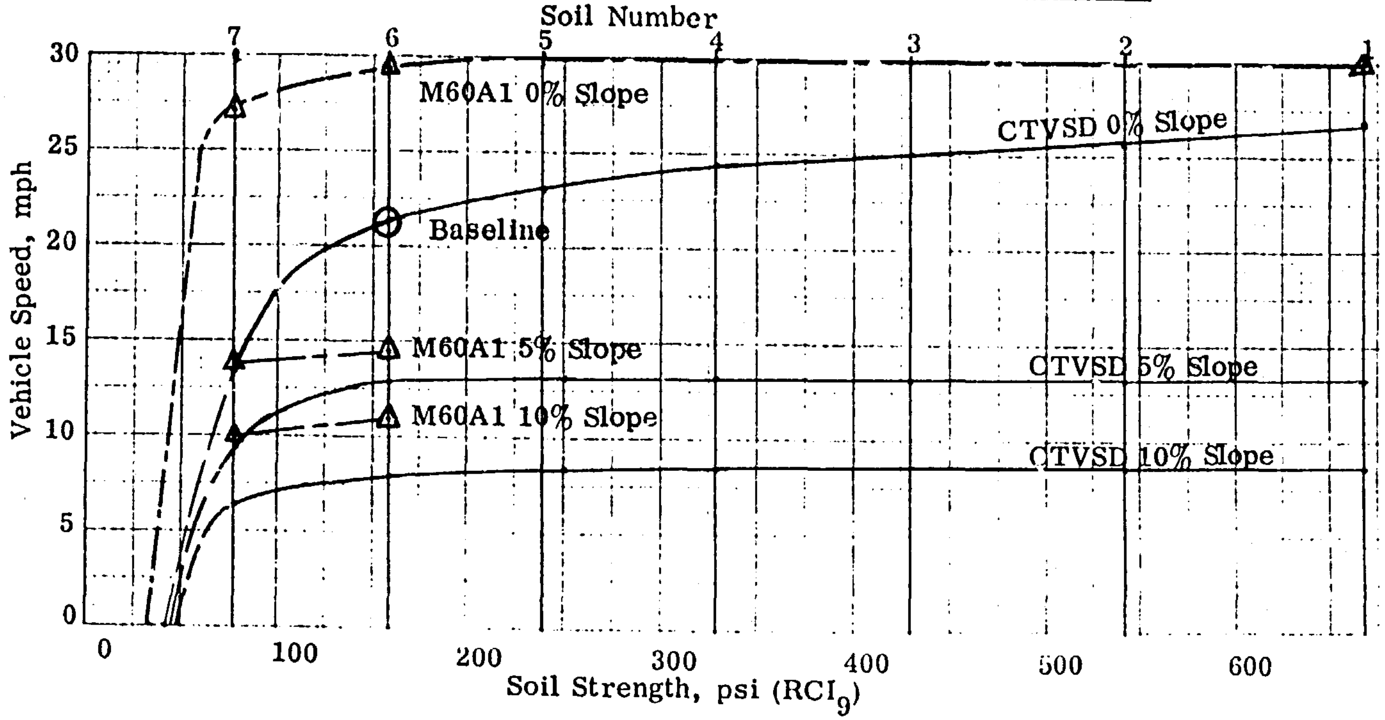


Figure 23 Soft Soil Mobility Comparison of M60A1 and Current CTVSD

	Left		Right	
At RCI_9 = 158 & 0% Slope	Front	Back	Front	Back
Quad Loading, lbs.	19,441	15,559	19,441	15,559
Sinkage, inches	1.06	.35	1.06	.35
Mean Ground Pressure, psi	17.04	7.01	17.04	7.01
Gross Traction, lbs.	18,698		18,698	
Drag, lbs.	488		488	
% Slip At 0% Slope	1.1		1.1	
5% Slope	3.9		3.9	
10% Slope	6.6		6.6	
Steering Effort, %	0			

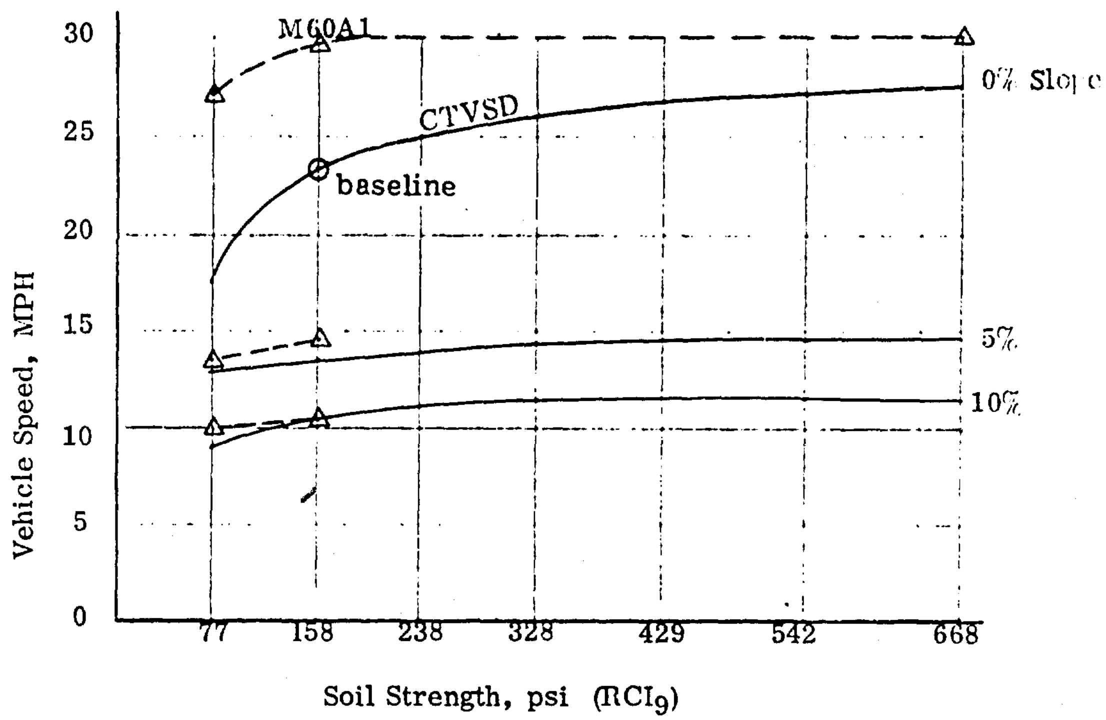


Figure 24 Soft Soil Mobility Comparison of M60A1 and Initial CTVSD

TABLE XXIV. SOFT SOIL MOBILITY OF TWO CTVSD CONFIGURATIONS
(Miles per hour for specified configuration and operating conditions)

Configuration No.	No. of Blasts Sust'd.	Blast-damaged Configuration: Right -- Left(5)	RCI_9 = 77, 0% SLOPE, Prelim(6)	RCI_9 = 77, 0% SLOPE, Current(6)	RCI_9 = 77, 10% SLOPE, Prelim	RCI_9 = 77, 10% SLOPE, Current	RCI_9 = 158, 0% SLOPE, Prelim	RCI_9 = 158, 0% SLOPE, Current	RCI_9 = 158, 10% SLOPE, Prelim	RCI_9 = 158, 10% SLOPE, Current	RCI_9 = 668, 0% SLOPE, Prelim	RCI_9 = 668, 0% SLOPE, Current	RCI_9 = 668, 10% SLOPE, Prelim	RCI_9 = 668, 10% SLOPE, Current
Front Only Damage														
D1	1	oo ooo oo ooo	0	2.1	0	0	0.4	1.5	0	1.9	19.9	19.4	8.0	6.0
A1	2	oo ooo oo ooo	0	2.8	0	0	2.2	5.2	0	3.2	20.8	20.7	9.8	7.4
E1	2	.o ooo oo ooo	0	0	0	0	0	1.9	0	0	9.8	10.2	5.7	5.2
(1)	3	.o ooo oo ooo	0	1.4	0	0	1.1	1.0	0	1.6	16.2	16.2	8.0	6.4
F1	3	.. ooo oo ooo	10.8	7.2	6.5	5.1	16.3	13.5	8.7	6.4	21.3	21.2	9.9	7.6
B1	4	.o ooo .o ooo	0	0	0	0	0	2.9	0	0	11.5	11.8	6.2	5.4
Front and Rear Damage														
A3	2	oo ooo oo ooo	0	0	0	0	1.1	0	0	0	19.5	13.0	7.5	2.1
(2)	3	oo ooo .o ooo	0	0	0	0	0	0	0	0	15.5	10.3	7.2	1.0
(2)	3	oo .oo oo ooo	0	0	0	0	0	0	0	0	15.5	10.3	7.2	1.0
B3	4	oo .oo .o ooo	0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(C3)	4	oo ooo .. ooo	10.2	7.0	6.4	1.8	16.1	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(B3)	4	oo ..o oo ooo	0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(B3)	5	oo ..o .o ooo	0	0	0	0	0	0	0	0	11.5	7.6	6.8	0
(C3)	5	oo .oo .. ooo	10.2	7.0	6.4	1.8	16.1	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(C3)	5	oo ... oo ooo	10.2	7.0	6.4	1.8	16.1	13.5	8.6	6.1	21.3	21.2	6.8	5.8
Rear Only Damage														
D3	1	oo ooo oo ooo	3.8	0	0	0	6.1	0	1.8	0	21.3	13.0	5.9	2.1
A2	2	oo ooo oo ooo	5.2	0	0	0	8.0	0	3.2	0	21.8	15.2	9.9	4.0
E3	2	oo .oo oo ooo	2.6	0	0	0	5.2	0	0	0	21.1	6.4	5.8	0
(3)	3	oo oo oo ooo	4.6	0	0	0	7.2	0	0	0	23.6	13.2	9.6	2.0
F3	3	oo ..o oo ooo	0	0	0	0	2.4	0	0	0	13.3	0	4.8	0
B2	4	oo .oo oo .oo	4.4	0	0	0	6.3	0	0	0	22.3	11.2	9.3	0
(B2)	4	oo ..o oo ooo	4.1	0	0	0	6.3	0	0	0	22.3	11.2	9.3	0
(C3)	4	oo ... oo ooo	10.2	7.0	6.4	1.8	16.4	13.5	8.6	6.1	21.3	21.2	8.8	5.8
(4)	5	oo ..o oo .oo	2.0	0	0	0	5.0	0	0	0	18.8	5.6	8.0	0
No Damage														
OK	0	oo ooo oo ooo	17.6	13.5	9.0	6.5	23.2	21.3	10.7	8.0	27.2	25.8	11.4	8.6

(1) Average of A1 and B1
(2) Average of A4 and B3
(3) Average of A2 and B2
(4) Average of B2 and C2
(5) Key to blast damage pictograms:
- oo = Quadrant intact
- oo = Track missing, wheels intact
- . = Wheel (and track) missing
- x = indicated quadrant carries no load

(6) Key to 450 Hp CTVSD designs:

CTVSD	GVW, Lb.	CG Location Inches from Front	Roadwheel Loading, Lb. Front	Roadwheel Loading, Lb. Rear	Track Width, In.
Preliminary	70,000	136.5	9,721	5,168	28
Current	95,859	164.1	9,586	9,586	25

quent mine blast under an untracked roadwheel will remove the roadwheel, regardless of the area of the roadwheel exposed to the blast wave. An increase in roadwheel width, therefore, would not increase blast damage probability.

The soft soil mobility of a CTVSD with untracked wheels will be improved by increasing wheel width. In theory, a 50 percent increase in wheel width, for example, will result in a 70 percent decrease in motion resistance. A similar reduction in load carried by the wheel will have a similar effect on motion resistance. Because of the difficulty of providing a blastworthy design with reduced weight, it is logical to increase roadwheel width for improved soft soil mobility.

Increased roadwheel width has another advantage in that it will provide greater protection to trailing undamaged quadrants. It is of greater mobility advantage to sacrifice a roadwheel rather than the track of an undamaged quadrant, especially since the removal of both tracks from one side of the CTVSD represents a mobility kill.

Weight reduction should also be considered as a method of further improving performance, but it is not evident that weight reduction is essential to achieve an effective CTVSD.

5.2.2.4 Conclusions

All conclusions in section 3.2.6 have been sustained, and the following additional conclusions can be noted:

- Equal wheel loadings from an optimum CG location improve soft soil mobility
- The CTVSD has a high probability of "go", even when extensively damaged
- Providing wider roadwheels is the most promising approach to increasing the number of mobile blast-damaged configurations

5.2.2.5 Recommendations

- Determine blast-damaged configuration probabilities of occurrence from threat analyses and design a rating system for mobility-related effectiveness
- Increase engine horsepower to at least 600

5.3 BLAST RESISTANCE

The blast effects model input data was updated to the current CTVSD configuration including weights, geometries, and functions of components. As in

section 3.3, an assessment of energy absorbed, axle loads and hull accelerations have been used as the primary indicators of the quality of the suspension system as an energy-absorbing mechanism.

5.3.1 Blast Model Inputs

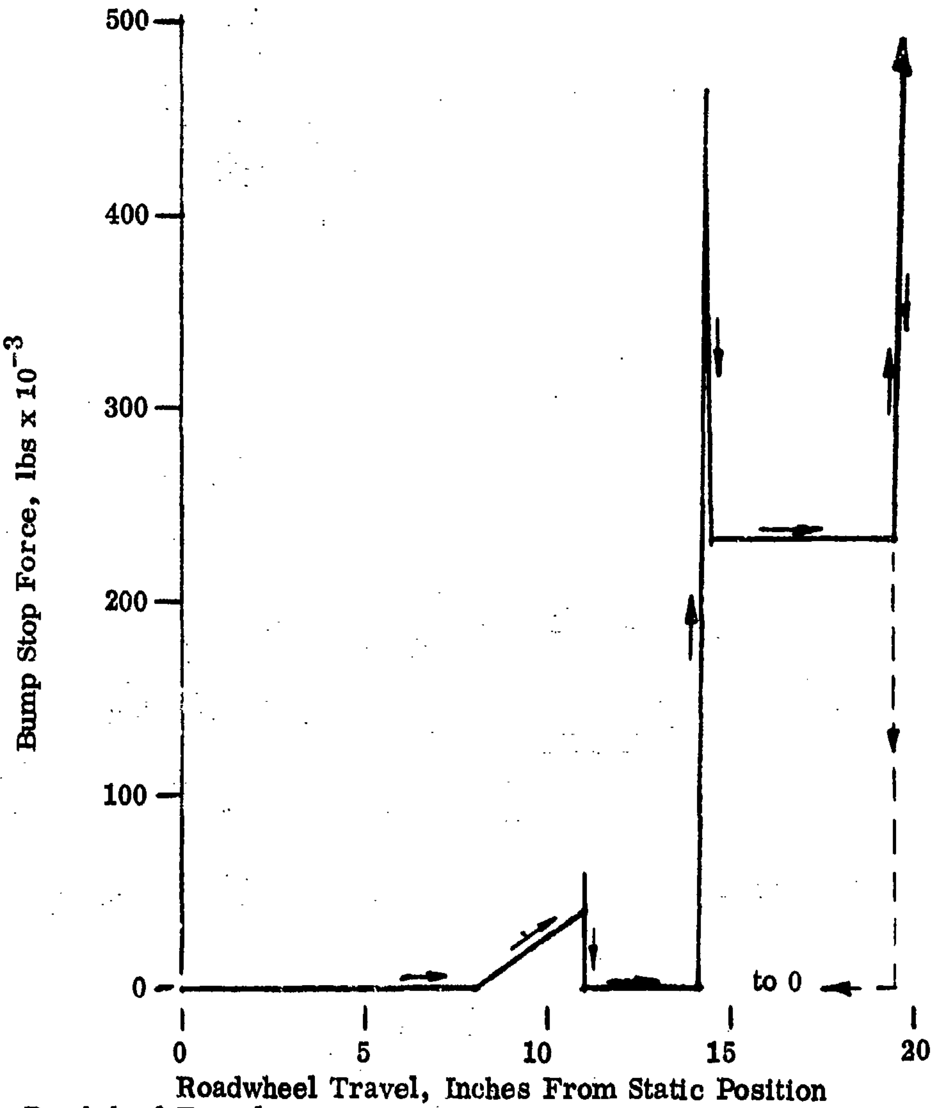
Data presented in table XXI describing the evolved configuration of the CTVSD was supplemented with additional details on the suspension springs (figure 21) and bump stops (figure 25). The torsilastic spring curve illustrates the slightly non-linear characteristic of the assembly. It is possible to safely wrap the spring a total of 82 degrees. When the energy-absorbing wheel bump stop is fully crushed, the maximum spring wind-up is 80 degrees.

The bump stop functional characteristics reflect the structural concepts derived to provide maximum isolation of the hull from blast-induced motions while protecting critical suspension components from damage. Energy management was of major concern and steps were taken to convert energy-storage devices to energy absorbing devices.

The blast effects model has indicated that roadwheel velocities during blast are far too large (up to 65 feet per second) to be accommodated by any conventional shock absorber that would be effective at the lower velocities encountered during cross-country operation. Since a blast-damaged CTVSD cannot maintain the high cross-country speeds demanded of the undamaged vehicle, there is no necessity of retaining a functional shock absorber. The shock absorber was, therefore, designed to fail and absorb blast energy. As the shock absorbers compress the first 0.5-inch under blast loading, the structural resistance of the two units will build from 0 to 100,000 pounds. At this loading, the shock absorbers are destroyed, absorbing about 2,000 lb-ft of energy.

Similar design consideration was applied to the need for preservation of mobility bump stops. In normal operation, they provide a positive jounce stop and protect the wheel blast bump stops from damage. These two rubber devices at each roadwheel station operate between 8 and 11 inches of jounce travel. In this 3 inches of compression, force from the two bump stops builds linearly from 0 to 40,000 pounds which is adequate for mobility purposes. Under blast conditions, these energy storage devices are converted to energy absorbers by allowing the mounting brackets to fail, removing another 5,000 lb-ft of energy from the system. As with the shock absorbers, the loss is of no consequence in mobility of the blast-damaged CTVSD.

After the bump stop has failed, the roadwheels and roadarms still contain 93,000 lb-ft of kinetic energy to be dissipated. To absorb this energy, a crushable honeycomb material was selected. From a wide range of available characteristics, a crush strength of 2,200 psi was selected and sized to blast bump stops capable of absorbing the residual energy. The total crush



Roadwheel Travel, Inches From Static	Event or Force Level, Bump Stop
8.0	Roadarms contact 2 mobility bump stops
11.0	Mobility bump stop force = 40,000 lb. Mobility bump stop bracket fails. Wheel bump stop bracket fails.
11.0-14.2	Wheel bump stop carried upward by wheels until free space is closed to the sponson.
14.4	Initial crush force of wheel bump stop max. at 463,200 lb.
14.5-19.5	Sustained crush force of wheel bump stop = 231,600 lb.
19.5	Wheel bump stop is solid, encounter structural spring rate of 10 lb/in
⟶	Load path

Figure 25 Bump Stop Functional Characteristics

of 5.3 inches under a sustained crush force of 231,600 pounds can absorb a total (per wheel station) of 102,290 lb-ft of energy. By being placed directly over the wheels, bearing loads in the wheel hubs are minimized. In combination, each wheel station has the potential of absorbing 109,290 lb-ft of energy before the blast-driven wheels impact solid structure.

Force input to the system was derived from figure 10. This derivation needs field validation, since it has direct impact on the adequacy of the structural loadings from blast.

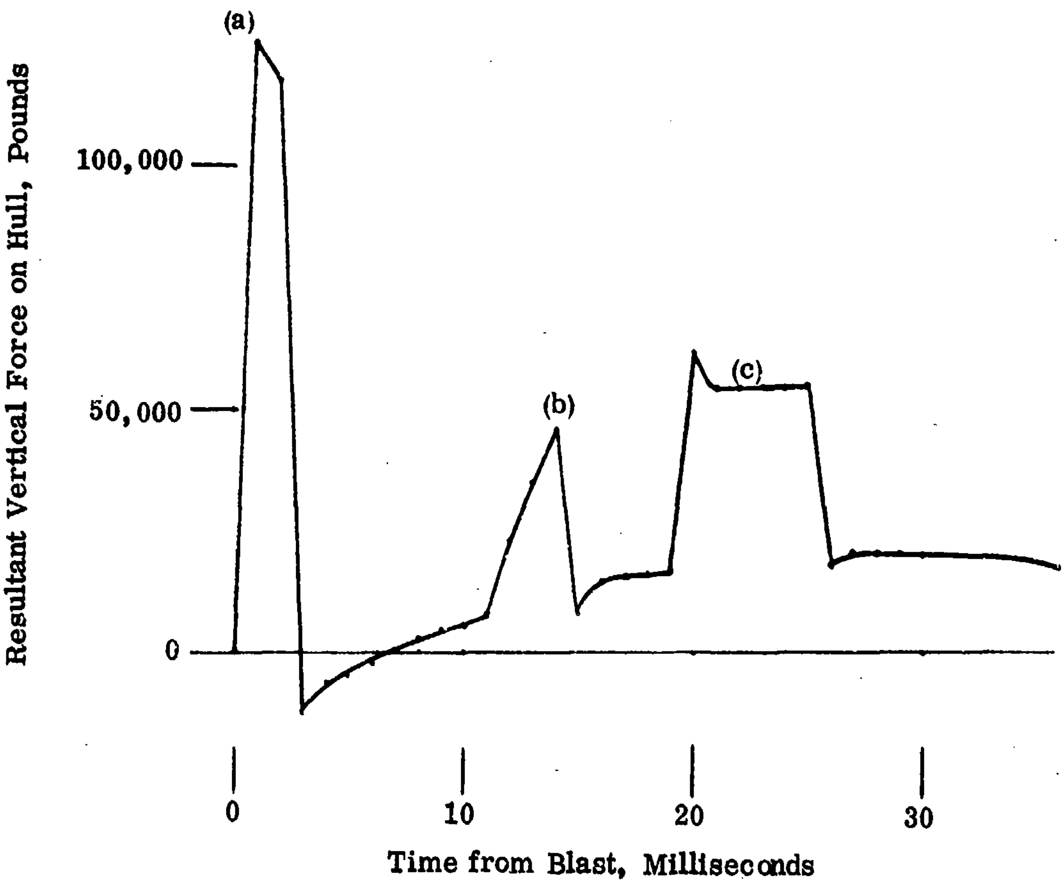
5.3.2 Blast Model Results

The computer analysis of motions and forces of the hull and suspension components has corroborated the adequacy of the design to manage the specified blast energy with an adequate margin. The effects of a blast under the number one wheel are summarized in table XXV. It is evident that the most critical blast environment is experienced during the first 2 milliseconds. The algebraic sum of forces acting on the hull is more nominal than the peak given in table XXV. Figure 26 shows the time-distribution of net forces acting on the hull. The principal origins of the forces are traceable through the data and are included in the graph.

TABLE XXV EFFECTS OF SPECIFIED BLAST ON CTVSD

TIME, MSEC	ITEM	MAXIMUM VALUE *
1	Vertical force on hull, pounds	126,000
1	Hull bounce acceleration, g	2.6
1	Hull pitch acceleration, radians per sec^2	32.6
0	Driver vertical acceleration, g (110 inches rearward of CG)	-7.3
1	Vertical force on roadarm, pounds	385,000
6	Roadwheel velocity, inches per second	784
36	Windup of torsilastic spring, degrees	61.9
36	Roadwheel travel, inches (19.5 possible)	16.9
36	Crush of roadwheel bump stop, inches (5.3 possible)	2.7

* These values are considered to be conservative, since system components were assumed to be rigid.



Principal origin of forces:

(a) Inertia of unsprung components and fracture of mobility shock absorbers

(b) Mobility bump stops

(c) Crush of wheel bump stops

Figure 26. Net Vertical Force on CTVSD Hull From Blast

5.3.3 Blast Effects on the Suspension Support Structure

A reassessment was made of the structural integrity of the suspension support structure. Critical loads are those imposed by an exploding mine at the outer edge of the track. The blast loads were computed for a 25-inch track.

The 2.5-inch plate specified in the suspension support structure is more than adequate to resist vertical blast loads. Lateral blast loads require that the plates be integrated with the hull structure in the rear quadrants. In front quadrants, gussets are required to supply needed bending strength to inside side plates. Without these treatments to resist the effects of blast side loadings, plate thicknesses would have to be increased. This can only be resolved by a complete structural integration of suspension and hull. In the meantime, the design presented here is believed to represent a reasonable weight claim for an adequate final structure.

It does not appear reasonable to expect that the CTVSD weight can be reduced significantly below the 95,859 pounds if component and structural survivability is to be retained. Roadarm and roadwheel weights are virtually fixed at the present values by the large blast loadings. Torsilastic spring size is not alterable. The suspension support structure weight has already been reduced by 20 percent from that of solid 2.5-inch plate. In spite of the resultant gross vehicle weight, the CTVSD is compatible in both weight and performance with the tanks it will precede.

If the blast occurs under the front roadwheel as assumed here, the crew is reasonably well isolated from the blast. While hull bounce acceleration produces an upward acceleration, the pitch acceleration counteracts this effect since the crew is located 110 inches behind the CG. At the instant of the blast, the crew's seats fall from beneath them. Therefore, the -7.3g acceleration is sensed as -1g. The acceleration at crew positions tends to remain slightly negative throughout the first 30 milliseconds. When the CTVSD pitches in the opposite direction, it will be driven solely by the torsilastic springs and should be well within tolerable limits.

Another important fact is illustrated in table XXV. The total energy of the blast is absorbed before the wheel bump stop has been fully crushed. Of the 5.3 inches of crush available, 2.7 inches was used, leaving a margin of unused energy absorption capacity.

The credibility of the results of this analysis depend upon the quality of the input assumptions. These should be validated by field measurements. If the assumptions prove to be reasonably accurate, then it is apparent that a structure can be designed to manage the blast energy, leaving critical components intact for continued mine-clearing operation.

5.3.4 Blast Effects Conclusions

- Blast energy of 100,000 lb-ft with an impulse of 2,250 lb-sec can be adequately managed by the evolved suspension system with a margin of safety.

- Integration of the suspension support structure and the hull is required to provide necessary structural rigidity.

5.3.5 Blast Effects Recommendations

- Since structural design depends heavily on the accuracy of input force assumptions, field validation is required, especially for blasts just outside the track.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This report is structured with conclusions and recommendations following discussion of each aspect of the work performed, such that the rationale is fresh in mind. This section will present these again as a basis for development of an overall set of conclusions and recommendations.

6.1 ANALYTICAL SECTION

6.1.1 Ride Dynamics

6.1.1.1 Conclusions

- The CTVSD can maintain the lead position in a column of M60A1 tanks.
- The demands placed on suspension design are reasonable.
- The design latitude afforded by acceptable ranges of suspension parameters has permitted attention to special requirements for blast resistance.
- Based on recommended levels for CTVSD suspension design, the CTVSD can match the M60A1 speeds over any of the six terrains used in this analysis, and these terrains are sufficient to cover terrains of major importance.
- The final version of the undamaged CTVSD will be able to pace a column of product-improved M60A1 tanks if adequate horsepower is provided.

6.1.1.2 Recommendations

- The evolution of the CTVSD design subsequent to this effort should account for ride dynamics in design/performance trade studies.

6.1.2 Soft Soil

6.1.2.1 Conclusions

- The soft soil performance of the undamaged CTVSD is compatible with that of the M60A1 tank.
- Most CTVSD blast damaged configurations remain mobile in soils of critical interest.

- A rearward shift of the CTVSD center of gravity to produce equal loading on all wheels improves soft soil performance in both undamaged and damaged configurations.

- Soft soil mobility degradation is related directly to the motion resistance of unpowered rigid wheels and associated loss of traction when a track is lost.

- An increase in horsepower of the CTVSD is needed to increase the speeds of the mobile configurations.

- The CTVSD has a high probability of "go" even when extensively damaged.

- Increase in roadwheel width is the single most promising item for increasing the number of mobile blast-damaged configurations.

6.1.2.2 Recommendations

- Determine blast-damaged configuration probabilities of occurrence from threat analyses and design a rating system for mobility-related effectiveness.

- The center of gravity of the CTVSD should be located such that each roadwheel receives approximately the same loading.

- The engine/transmission characteristics should be optimized specifically for the CTVSD to match M60A1 soft soil performance.

- Increase engine horsepower to at least 600.

6.1.3 Blast Effects

6.1.3.1 Conclusions

- Blast energy of 100,000 lb-ft with an impulse of 2,250 lb-sec can be adequately managed by the evolved suspension system.

- The dynamic response of the CTVSD suspension unit can be conservatively determined by a simplified computer simulation model.

- The roadwheel/roadarm weight ratio should be maximized to reduce axle forces.

- Standard mobility type shock absorbers do not significantly contribute to blast energy absorption. If standard automotive

shocks are used, the roadwheel bump stops must absorb most of the input energy.

- Special shock absorber devices with high forces acting over long strokes (up to 7 inches) would significantly contribute to blast energy management.

- Validation of the blast effects model by comparison with field test results is needed.

- Integration of the suspension support structure and the hull is required to provide necessary structural rigidity.

6.1.3.2 Recommendations

- More complete definition of the suspension unit structural response to high impulse loads is recommended. Particularly, methods of determining structural elastic and plastic deformation need to be considered in future analyses.

- Future simulation models should consider track effects on the suspension system. The impulse delivered to the system through mine detonation acts on the track exposed area, which is considerably larger than the roadwheel exposed area. At the present time, it is not known how the track responds to mine detonation.

6.1.4 <u>Structures</u>

6.1.4.1 Conclusions and Recommendations

- The object of arriving at a balanced design of suspension system has been met.

- Because of uncertainties associated with blast loads and simplified assumptions, the analyses must be considered preliminary.

- Adequate instrumentation must be provided in the test rig in order to obtain better definition of loads during blast.

- Adequate design of suspension brackets requires integration with CTVSD hull structure.

6.1.5 Analytical Overview

6.1.5.1 Recommendations

- Ride dynamics studies in the near future should be limited, since the variation of ride parameters allows considerable latitude in the selection of specific values.

- Soft soil mobility and performance studies, coupled with mine clearing effectiveness studies, should be performed to determine the critical blast damaged configuration and methods of improvement in design of these configurations to achieve greater mobility performance.

- The blast effects model should be improved with the addition of structural elastic and plastic deformation effects and a more specific representation of the mine blast phenomena as they interface with the structure.

- Test data should be correlated with structural and stress analysis data to upgrade the structural analyses and to provide more meaningful results and interpretations of analytically derived data. A complete hull/suspension system structural analysis is suggested.

6.2 DESIGN SECTION

6.2.1 Special Devices

6.2.1.1 Conclusions

- Special devices for energy management are candidates for the CTVSD.

- Hydraulic devices such as liquid springs can fit into an acceptable space envelope.

- Crushable devices such as honeycomb material can be designed to accept all of the energy input from the specified mine detonation.

6.2.1.2 Recommendations

- Consider special energy absorbing devices for the shock absorbers and roadarm and roadwheel bump stops.

- Investigate other methods of energy absorption that may be more applicable in terms of size, weight, and cost per unit of energy absorbed.

- Blast tests should be conducted with special energy absorbing devices installed in the suspension test rig to validate analytical results and to enable the selection of the particular combination of special devices.

- Continue investigation and design integration studies on special devices.

- Conduct further design studies on structure.

- Design a test fixture.

6.3 SYSTEM CHARACTERISTICS SECTION

6.3.1 Conclusions

All conclusions regarding mobility have been sustained after further analysis and the following additional conclusions can be noted:

- Equal wheel loadings from an optimum CG location improve soft soil mobility.

- The CTVSD has a high probability of "go", even when extensively damaged.

- Providing wider roadwheels is the most promising approach to increasing the number of mobile blast-damaged configurations.

- Blast energy of 100,000 lb-ft with an impulse of 2,250 lb-sec can be adequately managed by the evolved suspension system with a margin of safety.

- Integration of the suspension support structure and the hull is required to provide necessary structural rigidity.

6.3.2 Recommendations

- Determine blast-damaged configuration probabilities of occurrence from threat analyses and design a rating system for mobility-related effectiveness.

- Increase engine horsepower to at least 600.

- Since structural design depends heavily on the accuracy of input force assumptions, field validation is required, especially for blasts just outside the track.

6.4 OVERALL CONCLUSIONS

The major conclusions of the individual sections may be distilled as follows:

- CTVSD cross-country speed requirements can be met without undue compromise to other design requirements. Perhaps speed capabilities could be reduced if required to further enhance blast resistance, but not at the expense of reduced soft soil mobility of blast-damaged vehicles.

- Soft soil mobility of various damaged configurations appears good and can be upgraded with later design revisions, especially those which increase roadwheel width and reduce gross vehicle weight. Further evaluation of this capability should be tied to threat and system effectiveness studies.

- It appears that a suspension system design can be developed that is capable of withstanding the specified blast threat. Testing is required to validate this conclusion.

- Special devices, particularly liquid springs and crushable materials, show promise for upgrading blast resistance well beyond the specified threat.

- The projected system is feasible from the design standpoint. Further work on structural integration and investigation of special devices and wider roadwheels is required.

6.5 OVERALL RECOMMENDATIONS

- Refine and validate the blast effects model.

- Conduct structural integration studies, especially with a view to weight reduction.

- Continue investigation of special energy management devices and wider roadwheels.

- Design a blast test fixture.

- Evaluate projected capabilities in relation to the threat and to the capabilities of competing systems.

6.6 PROGRAM PLAN

The conclusions and recommendations presented in this section have an analytical/investigative orientation, since they are the product of a program comprised of analytical and design investigations. This orientation should not obscure the fact that the true imperative for continued progress is acquisition of blast test data on the test rig system described in paragraph 3.3. The other recommendations are subordinate to this imperative and are suggested primarily as a method for making additional progress during the period of hardware procurement. On this basis, the time-sequenced recommendation for a future program is as follows:

- Design blast test fixture
- Continue blast effects model refinement and design investigations
- Procure and assemble test rig hardware
- Conduct first-generation tests

These tests should be considered exploratory rather than definitive. It is probable that further rig tests will be recommended after another cycle of analytical and design investigations which incorporate the results of the first generation tests.

CTVSD feasibility remains to be demonstrated in hardware and it is not yet clear that the system will be more effective than other systems. The current view is sufficiently encouraging, however, to justify the recommendation that a program including the elements listed above be initiated. The reasons for this recommendation include:

- Studies by MERDC indicate that CTVSD is relatively effective against classic minefields
- CTVSD is the only known conceptual mine-clearing system that does not degrade base vehicle mobility
- CTVSD is the most viable concept in view for high speed mine-clearing of roads
- CTVSD may be the only candidate system that is effective against multiple-fuzed mines